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FACULTATIVE AND ALGAE PONDS FOR TREATING BEET SUGAR WASTES

James H. Fischer, et al

Beet Sugar Development Foundation
Fort Collins, Colorado

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PROGRESS REPORT III

June 1, 1965, June 30, 1967

Beet Sugar Development Foundation
Fort Collins, Colorado

Project Location
Tracy, California

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WPD 93-01
WPD 93-02
WPD 93-03 (partial)

WPD 93-01, 02

FACULTATIVE AND ALGAE PONDS FOR TREATING BEET SUGAR WASTES

WPD 93-03(Partial)

ANAEROBIC-AEROBIC SUGAR BEET WASTE TREATMENT

Beet Sugar Development Foundation
Fort Collins, Colorado

Project Location
Tracy, California

Project Director - James H. Fischer, M.E., Manager
Project Engineer - Ronald A. Tsugita, P.E.
Consultants: W. J. Oswald, Ph.D.
Clarence G. Golueke, Ph.D.
Robert C. Cooper, Ph.D.

June 1, 1965 - June 30, 1967

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SUMMARY

A total of 11 loadings with variable recirculation rates were used to demonstrate the effect of an anaerobic-facultative-aerobic treatment system (in series) on the degredation of dissolved and suspended solids characteristically found in beet sugar flume waste waters. The effect of these treatments on odors was also determined.

In the pond series, the major part of the removal of BOD, COD, volatile solids, coliforms and odor-causing substances takes place in the anaerobic pond. It is not possible to operate the anaerobic portion of the system without odor production, unless the surface is aerated by recirculation of oxygenated water or by mechanical aeration.

The apparent maximum rate of BOD and COD removal per acre per day took place at the heavier loading rates and in conjunction with the higher rates of recirculation. This essentially is true for total nitrogen removal, however, the trend is not similar in all runs. The removal of volatile solids followed the BOD, COD removal trends. The odor product was higher in the anaerobic pond, as expected. The higher odor product is not necessarily associated with the higher loading rates.

The 99.99% reduction of coliform and fecal streptococci is significant to the industry and to regulatory agencies.

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Progress Report III
Facultative and Algae Ponds
for Treating Beet Sugar Wastes

I. INTRODUCTION

This progress report covers the period June 1, 1965 through June 30, 1967. Part of the data and discussion, appearing in Progress Reports I and II are repeated to provide continuity. For the most part, repeated data appear in the figures and tables thus providing a better opportunity to understand trends and results.

In general, the plan of operation and test schedule has been closely adhered to. Those not immediately familiar with sugarbeet harvesting practices in warm climates such as California, must be reminded that precipitation of any consequence will terminate field harvesting operations. Climatic conditions, mostly the influence of temperature, prohibit storage of sugarbeet roots in a sufficient quantity to continue processing operations for more than a day or two beyond the termination of harvest.

This weather effect on treating flume water wastes was given some consideration in the plan of operation. However, the severity and length of intermittent precipitation during the spring of 1967 was not expected nor planned for. Fortunately, these interruptions have not been excessively influential on the data. Some of the responses to loading might have been somewhat different, particularly when certain runs were either shortened or divided due to an absence of raw influent.

None of this variance from normal is reported in the data or conclusions. It would be appropriate to mention that the pilot treatment system would respond rapidly to the erratic changes induced by weather. This becomes a factor in further demonstrating the application of the objectives of this study to the treatment of beet sugar wastes.

In spite of design and construction efforts aimed at minimizing mechanical malfunctions, the project has experienced its share of difficulties. It is appropriate to acknowledge the cooperation of the Operating Department personnel of the Holly Sugar Corporation at Tracy, California, for their responsive assistance during construction and maintenance phases of the project. If customary outside firms would have been required for repairs, down-time might have been influential on the data.

This project (WPD 93-01, 02 and 03) is designed to demonstrate, on a pilot basis, the application of the anaerobic-facultative-aerobic series treatment to the reduction of pollutants in beet

sugar factory wastes. Only a portion of the total quantity waste water from the Tracy mill has been subjected to this study. The portion diverted for treatment has depended upon the loading criteria established for each separate run. The quantity diverted is representative of the total.

II. PHYSICAL DESCRIPTION OF PILOT PLANT

Flume water from the Tracy mill is discharged through a concrete box into the existing lagoon system, where a 300 GPM pump lifts water 20 feet from the box to the top of a settling tank. The water is then passed through a Dorr-Oliver DSM screen. The filtrate enters the tank tangentially creating a cyclonic action that settles out the heavier particles. These solids are collected in a conical hopper located at the bottom of the tank and are discharged back into the commercial lagoons through a drain line. Detention time in the 14-foot high, 10-foot diameter tank is approximately 30 minutes. The discharge line is located at the top and center of the tank; a conical shield prevents floating scum from entering the pipe. The water flows by gravity to a Parshall flume box, for continuous metering. From the flume box the water flows into the anaerobic pond entering at the center and bottom of the pond (Figures 1, 2 and 3).

The anaerobic pond is approximately 15 feet deep and has a surface area of one acre. The discharge is located at the northwest corner of the pond. The depth of discharge is adjustable from 0 feet to 19 feet. A depth control weir through which the water flows, controls the depth of the anaerobic pond. Water from the weir flows into the facultative pond which is approximately 7 feet deep and has a surface area of 2 acres. Discharge from the facultative pond flows through another depth control weir and into the algae pond.

The algae pond has a depth of 3 feet (instead of the 5 feet in the plan) and a surface area of 3.4 acres. At the east end of the pond, water flows through another depth control weir and into a pump sump. An automatic 250 GPM pump discharges the water into a 3-inch Parshall flume where the water is metered continuously before discharge into the commercial lagoon drain ditch. The hydraulic characteristics of the ponds are shown in Table 1.

A skimmer and a drain line are located in the southeast corner of each pond. This location was selected because the prevailing wind is from the northwest. All drain lines empty into a central sump. The sump has three pumps, 200 GPM, 300 GPM and 500 GPM. The system can recycle from a minimum of 25 GPM to a miximum 1400 GPM. At present the recirculant is pumped through a 6-inch Parshall flume and into a junction box where it is mixed with the influent. The influent and recirculant then flow into the anaerobic pond.

Table 1. - Depth, surface area - volume relationships of anaerobic, facultative and algae ponds, Tracy, California.

Depth (feet)	Surface area (acres)	Volume (acre-feet)	Volume (gallons)
	ANAEROBIC POND		
1	0.36	0.35	114,00
2	0.40	0.72	235,00
3	0.44	1.15	375,000
4	0.48	1.61	525,000
5	0.52	2.12	691,000
6	0.56	2.66	867,000
7	0.60	3.26	1,062,000
8	0.65	3.91	1,274,000
9	0.70	4.61	1,502,000
10	0.74	5.37	1,750,000
11	0.79	6.18	2,013,000
12	0.85	6.99	2,277,000
13	0.90	8.00	2,606,000
14	0.96	8.99	2,929,000
15	1.01	10.04	3,271,000
	FACULTATIVE POND		
1	1.51	1.41	459,000
2	1.60	3.03	987,000
3	1.67	4.67	1,521,000
4	1.75	6.36	2,072,000
5	1.84	8.19	2,668,000
6	1.92	10.06	3,278,0
7	2.01	11.78	3,838,0
8	2.10	14.16	4,613,0
	ALGAE POND		
1	2.82	2.77	902,000
2	2.94	5.64	1,838,000
3	3.10	8.70	2,834,000
4	3.24	11.89	3,874,0
5	3.38	15.20	4,952,0

III. RESEARCH PLAN

Because of the limitations placed on time by the seasonal nature of the beet sugar processing operations and because of the large physical size of the pilot plant, the number of factors to be studied had to be restricted. Consequently, the study was principally concerned with the effects of two factors: amount of loading and rate of recirculation. Since at the time of the study, the series arrangement could not be varied, only one was used viz. anaerobic--facultative--aerobic. These two factors were selected because they are easily regulated at a minimum of expenditure. Of course, information on loading is essential because without it a feasible design could not be developed.

Variations in the applied loadings and recirculation rates as well as the sequence of the combinations of variables and duration of each run are presented in Table 2. Although it would have been desirable to have allowed the ponds to have reached "steady-state" in each run before making observations, exigencies of time imposed an upper limit, hence a compromise time of 15 days was allowed for each run. This time-period was long enough for a trend to be established and thus permit valid extrapolations.

Table 2. - Order of runs for 1966 and 1967.

Run #	Dates and years	Feed	Recirculation
1	March 11 to March 20, 1966	50	25
2	March 21 to March 31, 1966	50	0
3	April 1 to April 10, 1966	50	50
4	April 11 to April 26, 1966	50	75
5	September 26 to October 20, 1966	100	100
6	October 21 to November 8, 1966	100	50
7	November 9 to November 23, 1966	100	0
8	March 1 to March 15, 1967	150	0
9	May 1 to May 22, 1967	50	50
10	May 23 to June 5, 1967	260	260
11	June 6 to June 20, 1967	260	0

In addition to the major study of the effects of loading and recirculation, a number of small scale investigations were made of other factors which exert an influence on pond performance.

IV. METHODS AND PROCEDURES

Sampling

Samples were taken at 8:00 a.m. Monday through Saturday. Influent samples were given the designation "Sample 1" in the various experiments. They were 24-hour composites of samples taken from the feed line by means of a solenoid valve and reset timing device. The effluent samples, designated "Sample 2", were taken from the northwest corner of the anaerobic pond. Samples numbered 3 refer to the effluent of the facultative pond. These were taken at the northwest corner of the pond. Sample number 4 was the effluent from the algae pond, and was taken at the eastern end of the pond. Each sample had a volume of about 800 milliliters. The schematic diagram of the sampling stations is shown in Figure 4.

Determinations

A list of the determinations made in the research and their frequency is presented in Table 3.

Table 3. - Determinations and observations.

	M	T	W	T	F	S
Gravimetric solids:						
Total solids	X	X	X	X	X	X
Suspended volatile	X	X	X	X	X	X
Suspended ash	X	X	X	X	X	X
Dissolved volatile	X	X	X	X	X	X
Dissolved ash	X	X	X	X	X	X
Volumetric solids:	X	X	X	X	X	X
% algae	X	X	X	X	X	X
Algae counts	X	X	X	X	X	X
pH	X	X	X	X	X	X
Conductivity	X	X	X	X	X	X
Light penetration	X	X	X	X	X	X
Color	X	X	X	X	X	X
Odor	X	X	X	X	X	X
Water temperature	X	X	X	X	X	X
BOD	X		X		X	
COD filtered	X		X		X	
Unfiltered	X		X		X	
Dissolved oxygen a.m. and p.m.	X		X		X	
Gas analysis - CH_4, CO_2, O_2, CO, N	X		X		X	
Total nitrogen		X		X		X
Ammonia nitrogen		X		X		X
Nitrate nitrogen		X		X		X
Phosphate		X		X		X
Sulfate		X		X		X
Sulfide		X		X		X
Calcium		X		X		X
Magnesium		X		X		X
Coliform		Once a week				
Fecal coliform		Once a week				
Fecal streptococci		Once a week				
PHYSICAL OBSERVATIONS						
Ambient temperatures			Daily			
Pond temperatures - top of pond			Daily			
bottom of pond			Daily			
Wind velocity			Daily			
Relative humidity			Daily			
Precipitation			Daily			
Evaporation			Daily			
Solar energy			Daily			
Sky cover			Daily			

Table 3 (continued)

Mondays, Wednesdays and Fridays
Take out 5 day BOD
Set up 5 day BOD
Gravimetric solids
Volumetric solids
pH
Conductivity X 1
Light penetration
Chemical oxygen demand (COD) unfiltered
Chemical oxygen demand (COD) filtered
Dissolved oxygen
Algae counts - microscopic
Temperatures - top and bottom
Sol-A-Meter reading
Gas Analysis
Tuesdays, Thursdays and Saturdays
Total nitrogen
Ammonia nitrogen
Nitrate
Phosphate
Sulfate
Sulfide
Calcium
Magnesium
Gravimetric solids
Volumetric solids
pH
Conductivity X 1
Light penetration
Algae counts - microscopic
Temperatures - top and bottom
Sol-A-Meter reading

Organoleptic

1. Color - the following color index was used: black, grey, red-brown, blue-green and green. A numbered color intensity code was used which ranged from 1 to 5, 1 being light, 5 being the darkest. 2. Odor - odor was coded as follows: foul, 5; H_2S, 4; cow dung, 3; other odors, 2; no odor, 1. The numerical code for designating intensity of odor ranged from 1 to 6, 1 representing no odor, and 6 the strongest.

Biological Observations

Determinations were made of algae type and number; of the identity and number of algae grazers; of coliforms, fecal streptococcal, and total bacterial counts; and of the identity and number of purple sulfur bacteria. Identifications and determinations of number were made by personnel at the University of

California as part of a grant made by the Beet Sugar Development Foundation to the University of California. Algae and purple sulfur bacteria were counted by direct microscopic observation with the use of a "Brite-Line" Leamocytometer. Volumetric determinations of algae were made according to a procedure developed by Oswald et al, [Studies of Photosynthetic Oxygenation., Progress Report No. 8. S.E.R.L., University of California, Berkeley. 1965 (3)]. Lauryl tryptose lactose broth was used for coliform determinations; and confirmation was made with the use of brilliant-green bile lactose broth [Standard Methods for the Examination of Water and Waste Water (1)]. Fecal streptococci were enumerated according to the MPN method, using dextrose azide broth for the presumptive test and ethyl violet azide broth for the confirmed test. In the MPN determinations, three tubes in three dilutions were used.

Physical Observations

Air temperature and relative humidity were recorded by means of a hygrothermograph. Sunlight energy was recorded by means of a Yellott Sol-A-Meter. Observations were made of the wind velocity and direction, evaporation and precipitation at the site. Access also was available to records of similar observations made by the U. S. Weather Bureau at the Tracy pumping station and Stockton Airport. A copy of the latter data was received monthly from the weather bureau. Influent rate and effluent rate of the system were automatically recorded and the recirculation rate was controlled by valves. At each station, the water temperature, color and odor were observed daily. The water temperatures at the bottom of the ponds and at the top were taken by means of a telethermometer (Yellow Springs Instrument Company). Periodically, temperature profiles were made with the use of the telethermometer.

Chemical Observations

Unless otherwise specified, chemical determinations were made according to Standard Methods 1. Solids were determined according to the Millipore method (2 Analytical Methods, compiled by D. Jenkins, San. Eng. Research Lab., March, 1965). An Orsat-type gas analyzer was used for making the gas analyses. A La Monte Pomeroy kit was used for making the sulfide determinations.

The sugar content of the influent was determined in the laboratory, Holly Sugar Corporation by the polarimetric method. The sodium and potassium content of the water was determined in the laboratory of the Utah-Idaho Sugar Company at Midvale, Utah.

Data Processing and Statistical Analysis

Data scheduled for collection during each run resulted from the sampling described in Table 3. Items of data were placed on IBM cards (i.e., "punched") for storage and processing

by the Spreckels Sugar Company. Two programs for data processing were followed: In the first program, two different parameters such as temperature and algae growth were correlated. In the second program the formability percentile of any parameter was produced. These programs were developed by personnel at Sacramento State College. The data were processed at the University of California, Berkeley, as part of the previously mentioned grant to the University. The IBM card layout is shown in Tables 1, 2, 3 and 4 (Appendix I).

V. MICROBIOLOGICAL RESULTS AND DISCUSSION

Indicator Microorganisms

Summaries of coliform, fecal coliform and fecal streptococci results are given in Tables 4A, 4B and 5. The counts are listed in Tables 5 and 6 (Appendix I). The data presented in Table 4A represent a geometric average of all the bacterial information collected during the fall campaign while in Table 4B the data represent median values for data collected during the spring campaigns. After inspection of the data it was obvious that in this instance the median and geometric average were quite comparable. In Figure 4 is shown a schematic diagram of the pilot plant showing the various sampling points, A, B, C, I, II, III and IV.

Table 4A. - Geometric average of coliform, fecal coliform and fecal streptococci MPN Fall 1966.

Station	MPN per 100 ml X 10^4		
	Coliform	Fecal coliform	Fecal streptococci
A	5.1	0.6	145.0
B	19,400.0	651.0	778,000.0
C	1,910.0	543.0	6,920.0
I	60,400.0	2,620.0	63,400.0
II	92.0	1.0	178.0
III	7.2	0.7	6.0
IV	0.7	0.1	0.6

Table 4B. - Median values for same as above Spring 1967.

Station	MPN per 100 ml X 10^4		
	Coliform	Fecal coliform	Fecal streptococci
A	43.0	0.4	0.2
B	3,300.0	100.0	420.0
C	590.0	330.0	43.0
I	9,500.0	1,500.0	230.0
II	260.0	230.0	0.9
III	5.9	2.3	0.06
IV	0.2	0.4	0.002

Table 5. - Percent removal of coliform, fecal coliform and fecal streptococci through the pond system. Fall 1966 and Spring 1967.

Station	Coliforms		Fecal coliforms		Fecal streptococci	
	Fall 66	Spr. 67	Fall 66	Spr. 67	Fall 66	Spr. 67
Influent to system	Zero	Zero	Zero	Zero	Zero	Zero
Anaerobic effluent(II)	99.85	97.20	99.95	85.00	99.72	99.71
Facultative effluent(III)	99.98	99.93	99.97	99.85	99.92	99.97
Aerobic effluent(IV)	99.99	99.99	99.99	99.97	99.99	99.99

The indicator organism data for the fall 1966 campaign were obtained prior to the grant to the University of California and were derived by personnel other than that associated with the University of California group. There is some question regarding the reality of the extremely high counts reported for certain time-periods during that campaign. The spring 1967 data were obtained as a result of determinations made in the University of California laboratory, and are presumed to be reliable.

Algae

The data on algal numbers are given in Table 7 (Appendix I). No attempt was made to analyze the data at this time because they would have to be correlated with operational, climatological, and chemical factors in order to arrive at any meaningful conclusions. Because of the magnitude of the task, this correlation was reserved for a future report in which this phase will be emphasized.

Discussion

Indicator Microorganisms

The indicator microorganisms found throughout the pilot plant system arose from a number of sources. One such source was the flume water which is taken from Sugar Cut Slough, a small blind arm of the San Joaquin River, which receives treated domestic waste from the City of Tracy. While it contributed numerous coliforms and fecal streptococci, the main bulk of these organisms come from the beet washing operation. Microorganisms of definite human origin enter the system at point "C", Figure 4, a small septic tank.

Coliforms, fecal coliforms and fecal streptococci were rapidly reduced in number upon exposure to the first (anaerobic) pond, and the same rate of destruction continued in the following

two ponds. Data representing this decline are plotted in Figures 5 and 6 (Appendix II). Although the overall removal was approximately the same during the fall and the spring campaigns, the resistance of the various indicator organisms relative to each other was different in each campaign. During the fall season the fecal streptococci appeared to be somewhat more resistant than were the fecal coliforms. This is what one normally would expect. Nevertheless, during the 1967 spring season, fecal streptococci were destroyed at the same rate as were the fecal coliform and were always fewer in number. From these results it would appear that the application of the fecal coliform to fecal streptococci ratio (FC/FS) for the determination of contamination source (suggested by Geldreich*) would not be applicable in this situation. Although past experience with systems for the treatment of agricultural wastes led to the expectation of a very low FC/FS ratio, the results show that this was not the case in the spring run. Varying the BOD loading and recirculation rate did not have an appreciable effect on numbers of indicator microorganisms throughout the system.

Regardless of the various anomalies indicated by the data, the percent reduction of coliforms and fecal streptococci within this treatment system was 99.99 percent in practically all cases (Table 5). This is particularly significant both to the beet sugar industry and to regulatory agencies, since it demonstrates that such a system can be relied upon to reduce the number of indicator microorganisms in the final effluent to levels satisfactory to all concerned.

VI. CHEMICAL RESULTS AND DISCUSSION

Sulfates and Sulfides

A major problem encountered in making the sulfate and sulfide analyses was one of silicon interference. The problem was solved with the application of the procedure given for the removal of silicon in Standard Methods. The results of the sulfate and sulfide analyses are tabulated in Table 8 (Appendix I). The amounts of sulfate removed and of sulfide produced per day and their relationship to COD and BOD loading are given in Table 6. It should be noted that the sulfate and sulfide data for runs 5, 6, 7 and 8 were not corrected for silicon interference. Consequently, any discussion of these experiments is limited to results for experiments 9, 10 and 11.

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*Geldreich, E. E. (1966) Sanitary significance of fecal coliforms in the environment. Dept. of Interior, Water Pollution Control Research Series Pub. No. WP-20-3. 122 pp.

Table 6. - Relationship between COD and BOD loading and sulfate removal and sulfide production.

Run	Feed 1000 gal/day	Recycle 1000 gal/day	COD loading lbs/acre/day	BOD loading lbs/acre/day	Sulfate removal lbs/acre/day	Sulfide production lbs/acre/day
			ANAEROBIC POND			
5	144	144	2980	1250	683	2.0
6	144	72	2250	1020	430	2.3
7	144	0	1920	1390	-	-
8	216	0	2430	1240	317	0.8
9	72	72	845	413	108	0.9
10	394	394	4450	2180	677	2.1
11	394	0	4160	2240	543	2.1
			FACULTATIVE POND			
						Sulfide removal
5	144	144	1492	490	8.2	2.0
6	144	72	671	381	49	2.7
7	144	0	359	249	-	-
8	216	0	290	149	60	0.8
9	72	72	108	48	0.7	1.0
10	394	394	798	420	61	4.7
11	394	0	555	225	20	2.0
			ALGAE POND			
						Sulfide removal
5	144	144	501	83	0.3	0.0
6	144	72	335	190	-16.5	0.1
7	144	0	198	130	-	-
8	216	0	67	33	9.1	0.0
9	72	72	33	8	2.7	0.0
10	394	394	287	122	-15.0	0.5
11	394	0	147	50	-30.0	0.6

Sulfate removal seemed to reflect COD loading in the anaerobic and facultative ponds since the highest removals in terms of tons per acre accompanied heaviest COD and BOD loadings. Apparently sulfates were released in the algae pond and a reverse order in production took place. At a loading of 287 lbs COD/acre/day a net increase of 15 lbs/acre/day was noted in the algae pond, and at 147 lbs/acre/day, the increase was 30 lbs/acre/day. The same relationship seemed to prevail with respect to sulfide productions.

Discussion

Sulfates and Sulfides

The sulfate and sulfide data are difficult to assess. However, values obtained for sulfate removal from the anaerobic pond are large enough to be truly significant. Removal of sulfur certainly is expected to take place under anaerobic conditions. The amount of sulfide produced in the anaerobic pond does not jibe with that of the $SO_4^{\equiv}$ removal. The discrepancy may be due partially to experimental error in conducting the analyses, and hence is only apparent in nature; and it may be partially due to the activity of purple-sulfur bacteria present in the pond. The bacteria easily could oxidize the amount of sulfide that could be produced from the amounts of $SO_4^{\equiv}$.

Again, it is to be expected that the extent of $SO_4^{\equiv}$ would decline as the wastes progress through the pond system. This is true because the facultative and algae ponds are aerobic (at least partially) in nature. In fact, the situation becomes so reversed that in the algae pond, $SO_4^{\equiv}$ is produced rather than removed.

Apparently, recirculation rate had some effect on sulfate removal, since at equal detention periods, but with different recycling rates, the sulfate removal was greater in the ponds receiving a greater degree of recirculation. This may even hold true for the anaerobic pond in runs 10 and 11. The detention periods were equal in these two runs; while the recirculation rate was 394 X 10^3 gal/day in run 9, and 0 gal/day in run 10. The removal in run 10 was 25% less than that in run 9, whereas COD loading in run 9 was only 7% greater than that in run 10. The same statements (except for numerical values) can be made for removals in the facultative and algae ponds.

VII. RESULTS FOR BOD AND COD

As stated previously, with regard to waste treatment, the experimental work thus far has been designed to determine the effects of loading, recirculation and series operation on the performance of the pond system when the mode of series operation was to pass the waste water through a series of three ponds. In the original design of the experimental system, one pond of the

three-pond series was constructed to emphasize the anaerobic phase in waste decomposition, a second to supply the facultative phase and a third, the aerobic phase. The sequence of passage of the waste water through the system was as follows: anaerobic pond, facultative pond, aerobic pond. The anaerobic pond was designed to operate at a depth of 15 feet, thus creating a potentially intensely anaerobic environment at its bottom. The facultative pond was designed to be 7 feet deep so that its surface could be aerobic and its bottom anaerobic. The algae pond was designed to operate at a depth of about 3 feet, thus being potentially aerobic throughout its depth.

Because of many conflicting factors these ideals were not always attained in all of the series. For example, in runs 5, 6 and 7 in which the objective was to study the effect of recirculation, partially treated waste water from the adjacent Holly sugar waste holding lagoons was added to the algae pond to bring it to the desired level, viz. 3 ft. This type of addition resulted in an overloading of the algae pond, and a breakdown in the photosynthetic aeration mechanism which persisted throughout the fall campaign. Subsequent analytical work indicated that the waste applied directly to the algae pond contained a much higher organic content than that which the pond previously had received. An oxygen deficiency and the presence of copper in the waste further contributed to a inhibition of algae growth. In spite of these problems a considerable amount of information was obtained.

BOD Removal

Effect of Loading

The effect of BOD loading on the removal of BOD in the anaerobic pond is indicated by the curve shown in Figure 7 (Appendix II). According to the figure, within a range of loadings of 450 to 2250 lb/acre/day, BOD removal increased in direct proportion to loading, varying from about 60% to about 80% as the loading was increased.

In Figure 8 (Appendix II) is shown the effect of loading in BOD removal in the facultative pond. Loading to this pond was varied from 50 to 500 lb/acre/day. Removal ranged from 40 to almost 400 lb/acre/day. Except in runs 6 and 7 in which the removal was about 50% of the applied load, approximately 80% of the BOD was removed.

The effect of loading on BOD removal in the algae pond is shown in Figure 9 (Appendix II). Here, the loading was varied from 10 to 200 lb/acre/day. Very little removal, i.e., from less than 7% to only 40%, occurred in runs 5, 6 and 7. It was in these runs that the pond was filled with the partially treated flume water from the Holly Ponds.

Effect of Recirculation

The curve in Figure 10 (Appendix II) indicates the effect of recirculation on BOD removal in the anaerobic pond. According to the figure, the most extensive removal of BOD occurred when there was no recycling. It diminished when the recirculation rate was 75,000 gal/day, and increased again when the rate was increased to 375,000 gal/day.

With the exception of the lowest rates, the influence of recirculation on BOD removal in the facultative pond is shown in Figure 11 (Appendix II). As the curve indicates, recirculation apparently had a positive effect on BOD removal. In Figure 12 (Appendix II) is indicated the effect of recirculation of BOD removal in the aerobic pond. Apparently removal at first increased with recirculation and then decreased. The decrease was not as great as that which took place in the anaerobic and the facultative ponds.

Effect of Series Arrangement

In Figure 13A and B (Appendix II) is shown the effect of series arrangement on BOD removal. In all of the runs, removal was greatest in the anaerobic pond; less in the facultative pond, and least in the aerobic pond.

COD Removal

Effect of COD Loading

The influence of loading on COD removal in the anaerobic pond is shown in Figure 14 (Appendix II). Loading was varied from 500 to 4,000 lb COD/acre/day, and removal ranged from 350 lb to 3700 lb/acre/day. Run 5 represented the only departure from this trend. (It was in run 5 that the partially treated flume water was added to the algae pond.) Except during run 5, removal of COD varied from 70% to 80%.

COD removal as a function of COD loading in the facultative pond is shown in Figure 15 (Appendix II). COD loadings varied from 125 lb/acre/day to nearly 1500 lb/acre/day. Removals ranged from 65 lb/acre/day to nearly 1,000 lb/acre/day. The performance of the facultative pond was not as strongly affected in runs 5, 6 and 7 as was that of the anaerobic and algae ponds. However, the lowest percentage COD removal, viz. 58%, occurred during run 7. Highest percentage removal was attained in run 8 in which the loading was 260 lb/acre/day and no recirculation was applied. Under these conditions, a removal of almost 85% was accomplished.

In Figure 16 (Appendix II) is shown the influence of COD loading on COD removal in the algae pond. The unusual effect resulting from the discharge of partially treated waste directly into the algae pond in runs 5, 6 and 7 is indicated in this figure. It should be noted that during these three runs, few algae could

be found in the pond. However, in the other runs, various concentrations of algae were present. Not including runs 5 and 6, percentage removal ranged from 7% to 37%.

Effect of Recirculation

The effects of recirculation on COD removal in the anaerobic pond are indicated by the curve in Figure 17 (Appendix II). Although the data are quite erratic, there is some indication that COD removal was relatively high when no recirculation was applied, and apparently decreased at the lower rates of recirculation. On the other hand, it increased with the application of high recirculation rates. Removals ranged from 350 to 3600 lb/acre/day.

With the exception of runs 5, 6 and 7, removal of COD in the facultative pond increased with increases in recirculation rate in the facultative pond, as is shown by the curve in Figure 18 (Appendix II). As the recirculation rate was increased from 0 to nearly 400,000 gal/acre/day in runs 9, 10 and 11, removals rose from 320 to 500 lb/acre/day. In runs 1, 2, 3 and 4 variation in recirculation rate from 0 to 108,000 gal/day was accompanied by increases in removal ranging from 90 to 170 lb/acre/day.

COD removal in the aerobic pond as a function of recirculation rate is indicated in Figure 19 (Appendix II). When the excessive load was applied instantaneously in runs 5, 6 and 7, an inverse relationship existed between increase in recirculation rate and BOD removal. No conclusions can be drawn on the basis of data obtained in run 3. Runs 9, 10 and 11 were characterized by a decrease in COD removal at the lower recirculation rates and an increase at the higher rates. Minimum removal was 10 lb/acre/day with no recirculation. Maximum removal 71 lb/acre/day took place with the recirculation rate at 375,000 gal/day.

Effect of Series Arrangement

The observed effect of series arrangement on COD removal is shown for all runs in Figure 20 (Appendix II). The results clearly indicate the existence of a cascade effect, in that removal dropped as the amount of material remaining to be removed declined. Removals ranged from 350 to 3600 lb/acre/day in the anaerobic pond. Removals were most extensive at the highest loadings. However, the COD of the effluents were too high to be acceptable in the environment without further treatment. In all cases removals in the facultative pond were less than those in the anaerobic pond, varying from 50 to 500 lb/acre/day. Removals in the algae pond always were lower than those in the facultative pond. They ranged from 7 to 70 lb/acre/day.

COD:BOD Ratio

In studies concerned with the correlation between the COD and the BOD of the raw flume waste, it was found that the ratio of COD to BOD was about 1.6. The size of the ratio indicates

the degree of treatment of the organic matter, since it reflects the size of the fraction of the organic matter which remains susceptible to biological oxidation. Thus, a COD:BOD ratio of 1.6 indicates that 63% of the COD is biologically available within 5 days, whereas a COD:BOD ratio of 3.0 indicates that only 33% of the organic matter remains biodegradable.

Effect of BOD Loading

The observed influence of BOD loading on the COD:BOD ratio in the anaerobic pond is shown in Figure 21 (Appendix II). With the exception of series 5, 6, 7 and run 11, little evidence of a change in ratio exists beyond the initial change from 1.6 to 2.0. This change evidently occurred independently of factors such as detention period and loading (i.e., up to 2250 lb/acre/day).

In Figure 22 (Appendix II) is indicated the effect of BOD loading on the COD:BOD ratio in the facultative pond. Again, no consistent patten is evident. In runs 5, 6 and 7, a positive correlation was observed while a negative correlation was noted in runs 8, 9, 10 and 11. Apparently however, the ratio became greater than 2:1 at the longer detention periods and at the lower recirculation rates. No ratios are given for runs 1, 2, 3 and 4 since no reliable BOD data were available.

The effect of BOD loading on the COD:BOD ratio in the algae pond is shown in Figure 23 (Appendix II). A positive correlation seems to exist between BOD loading and COD:BOD ratios in runs 8, 9, 10 and 11. The increased COD:BOD ratio could result either from a decrease in BOD or an increase in COD. In some cases the increased COD was due to algal growth.

Effect of Recirculation

The relation between recirculation and COD:BOD ratio in the anaerobic pond is indicated in Figure 24 (Appendix II). Evidently a positive correlation existed between the recirculation rate and the COD:BOD ratio, indicating that the biological availability of organic matter was in some way decreased by recirculation. In the case of the anaerobic pond this may have been due to a reduction in available BOD.

The effect of recirculation on the COD:BOD ratio in the facultative pond is shown in Figure 25 (Appendix II). Data obtained in runs 5, 6 and 7, which show a positive correlation, are inconsistent with those obtained in runs 9, 10 and 11, which in turn show an inverse correlation. Since, as stated earlier, distortion could have occurred in runs 5, 6 and 7, results obtained in those runs should be regarded as being less significant than those obtained in series 8, 9, 10 and 11. Therefore, it appears that as recirculation was increased, a decrease in stability occurred. This is consistent with the fact that with recirculation, water was moved from the anaerobic pond to the facultative pond.

The relation of the COD:BOD ratio to recirculation rate in the algae pond is shown in Figure 26 (Appendix II). According to the data, a consistently positive correlation existed between rate of recirculation and COD:BOD ratio, indicating that increased stability accompanied increase in rate of recirculation. In runs 8, 9, 10 and 11 algae were present, whereas there were no algae in runs 5, 6 and 7. As is to be expected the presence of algae increased the COD:BOD ratio.

Effect of Series Arrangement

In Figure 27 (Appendix II), the effect of series arrangement on the COD:BOD ratio is indicated. It is clearly evident in this figure that the tendency of ratio was to increase through the series. For reasons stated earlier in the report, runs 5, 6 and 7 constituted exceptions to this trend. The increase in ratio in the algae pond is attributable to algae growth and to improved BOD reduction brought about by the presence of the additional oxygen released by the algae.

VIII. RESULTS FOR TOTAL NITROGEN, VOLATILE AND SUSPENDED SOLIDS

Total Nitrogen

Changes in total nitrogen concentration may reflect variations in one or all of the following: 1. waste quality; 2. rate of denitrification (if it is taking place); 3. biological assimilation.

Effect of BOD Loading

The relation of BOD loading to the total nitrogen concentration in the anaerobic pond is indicated in Figure 28 (Appendix II). If a mean value of about 400 lb/acre/day be assumed for the nitrogen in the influent, it would appear that nitrogen decreased drastically at low loading, and that the amount of nitrogen discharged increased somewhat as the loading was increased. The nitrogen level reported for run 5 probably reflects the level of nitrogen in the partially treated waste water used to fill the ponds, but this apparently was drastically reduced in runs 6 and 7. In most runs nitrogen was equal to less than 2% of the BOD load.

The effects of loading on total nitrogen in the faculative pond are shown in Figure 29 (Appendix II). It is evident that total nitrogen concentration increased with increase in the BOD load. Loss of nitrogen was greatest at low loadings, and least at high loadings. The range of variation in the nitrogen content of the pond liquid was from 3% to 7%. Nitrogen losses in runs 5, 6 and 7 are probably distorted due to the excessive loading applied to the system in the form of partially treated waste water.

Nitrogen concentration as a function of BOD loading in the algae pond is plotted in Figure 30 (Appendix II). The nitrogen concentration in the pond remained about 9% of the BOD at all BOD loadings. For reasons previously stated, runs 5, 6 and 7 constituted exceptions to the trend.

Effect of Recirculation

The effects of recirculation on total nitrogen in the anaerobic pond are shown in Figure 31 (Appendix II). In runs 5, 6 and 7 in which the ponds were operated with partially treated waste, the nitrogen concentration increased with increase in recirculation rate. In runs 8, 9, 10 and 11, with the recirculation rate at 75,000 gal/day, the nitrogen concentration decreased; whereas it increased with the recirculation rate at 375,000 gal/day.

The relation of total nitrogen content to recirculation rate is shown in Figure 32 (Appendix II). In runs 5, 6 and 7, in which the ponds were operated with partially treated flume water, the nitrogen content increased linearly from 9 lb/acre/day at no recirculation to 27 lb/acre/day at a recirculation rate of 150,000 gal/day. In runs 8, 9, 10 and 11, the nitrogen content decreased at the lower recirculation rates, but increased as recirculation rate was increased from 75,000 to 375,000 gal/day.

In runs 5, 6 and 7, the nitrogen content of the algae pond increased sharply and then declined somewhat as the recirculation rate was stepped up from 0 gal/day to 75,000 gal/day as shown in Figure 33 (Appendix II). The nitrogen content again increased with increase in recirculation rate within the range of 75,000 to 375,000 gal/day.

Effect of Series Arrangement

In Figure 34 (Appendix II), the effect of series arrangement on the total nitrogen content of the various ponds is shown. According to the figure, nitrogen removals on the order of 75% were attained in the pond series. Most of the nitrogen removal was accomplished in the anaerobic pond. A slight incremental removal took place in the facultative pond. Increase or decrease in removal between the facultative and aerobic pond was only minor.

Volatile Solids

Amount of and changes in the BOD, COD and volatile solids content reflect the quantities of oxidizable substances added and removed in the biological treatment of a waste.

Effect of BOD Loading

The effect of BOD loading on removal of volatile solids in the anaerobic pond is shown in Figure 35 (Appendix II).

Judging from the data, volatile solids removal was about 1.33 times the BOD loading. However, exceptions occurred in runs 5, 6 and 7, and in runs 10 and 11.

The relation of BOD loading to removal of volatile solids in the facultative pond is indicated in Figure 36 (Appendix II). A positive correlation was observed in all of the runs although the reduction in volatile solids was greater in runs 8, 9, 10 and 11 than in runs 5, 6 and 7. In the former, removals were approximately two times the BOD load.

Volatile solids removal as a function of BOD loading in the algae pond is shown in Figure 37 (Appendix II). As is evident from the figure no removal took place in runs 5, 7 and 10; whereas removals were linear and about equal to loading in runs 8, 9 and 11.

Effect of Recirculation Rate

The effects of recirculation rate on volatile solids removal in the anaerobic pond are shown in Figure 38 (Appendix II). In runs 5, 6 and 7, volatile solids removal increased with increase in loading. Removal decreased in run 9, with the recirculation rate of 75,000 gal/day. However, it increased when the rate was increased to 375,000 gal/day. At the latter rate, volatile solids removal exceeded 4,000 lb/acre/day.

The relation between recirculation rate and volatile solids removal in the facultative pond is shown in Figure 39 (Appendix II). In runs 5, 6 and 7 removals increased with increase in recirculation rate within the range 0 to 144,000 gal/day. Removals ranged from 125 lb/acre/day at a recirculation rate of 75,000 gal/day to 1250 lb at a recirculation rate of 375,000 gal/day in runs 8, 9 and 10.

The curve in Figure 40 (Appendix II) shows the effect of recirculation rate on volatile solids removed in the algae pond. No volatile solids removal occurred in runs 5, 6 and 7 at any of the applied recirculation rates. In runs 9 and 10, volatile solids removal was less when recirculation was applied than it was in the absence of recirculation. The lessening of volatile solids removal in these two runs was a function of algae growth.

Effect of Series Arrangement

The relation between loading and volatile solids removal in the pond series is shown in Figure 41 (Appendix II). As is evident from the figure, removals exceeding 4,000 lb/acre/day were attained in run 10, while removals ranging from 500 to 1800 lb/acre/day took place in the other runs.

Packed Volume of the Suspended Solids

Effect of BOD Loading

Judging from the results obtained in the study, the packed volume of the suspended solids in the anaerobic pond varied linearly with increase in BOD loading. With the loading at 25,000 lb/acre/day, the packed volume of the solids was about 4 ml/l. The packed volumes of the solids in the facultative pond varied from 0.3 ml/l to 2.5 ml/l. In series 5, 6 and 7 a positive relationship existed in which packed volume increased from 1.4 ml/l at a loading of 250 lb/acre/day to 2.5 ml/l at a loading of 490 lb/acre/day. On the other hand, in runs 8, 9, 10 and 11, the packed volume decreased from 0.6 ml/l, at a loading of 50 lb/acre/day to 0.3 ml/l at a loading of 420 lb/acre/day.

The packed volumes of solids from the algae pond were 3.7, 3.7 and 1.3 ml/l at loadings of 80, 180 and 130 lb of BOD per acre respeccively in runs 5, 6 and 7. On the other hand in runs 8, 9, 10 and 11 packed volumes of 0.5, 0.6, 0.4 and 0.5 ml per liter were obtained for loading of 30, 10, 120 and 50 lb of BOD per acre.

Effect of Recirculation Rate

Results obtained in the runs with respect to effect of recirculation rate on packed volume proved to be inconclusive. The packed volumes of the suspended solids in the anaerobic pond in runs 5, 6 and 7 were 6.0 ml/l at a recirculation rate of 75,000 gal/day, and 14.2 ml/l at 144,000 gal/day. In runs 8, 9, 10 and 11 the packed volume was 2.4 ml/l and 1.3 ml/l when no recirculation rate was 75,000 gal/day; and increased to 4.8 ml/l when the recirculation rate was 375,000 gal/day.

The packed volumes of the solids in the facultative pond in runs 5, 6 and 7 were 4.0, 5.4 and 7.4 ml/l when the recirculation rates were 0, 75,000 and 144,000 gal/day respectively. In run 8, the packed volume of suspended solids of the facultative pond was negligible. On the other hand, in run 11, the packed volume was 8.6 ml/l at no recirculation, and 7.7 ml/l at 75,000 gal/day, and 8.0 ml/l at 375,000 gal/day. The packed volumes of the solids in the algae pond in runs 5, 6 and 7 were 3.7, 3.7 and 1.3 ml/l at recirculation rates of 144,000, 75,000 and 0 gal/day respectively. In runs 8 and 11, the packed volumes were 0.5 ml/l. The packed volumes in run 9 were 0.6 ml/l at a recirculation rate of 75,000 gal/day, and 0.4 ml/l at a recirculation rate of 375,000 gal/day.

Effect of Series Arrangement

Of the three ponds, the suspended solids of the anaerobic pond had the greatest packed volume. The packed volumes of the solids in the algae and facultative ponds were equal to each

other, but less than those of the anaerobic pond. Packed volumes varied from a low of 0.3 ml/l for the algae pond to a high of 8.5 ml/l for the anaerobic pond.

IX. RESULTS FOR ODOR, pH, ANCILLARY STUDIES AND DISSOLVED OXYGEN

Odor Production

Odor production is expressed as an "odor product" to which is assigned a numerical value based on two scales each of which is graded 1 through 6. The first scale relates to the type of odor, its numerical value increasing with increase in objectionability; and the second to the intensity, with increase in intensity accompanied by increase in numerical value. As the term implies, the numerical value of the odor product is the product of the numerical value of the quality scale times that of the intensity scale. Thus, for any odor production, 1 represents the lowest "odor product" and 36 the highest.

Effect of Loading

The "odor product" for the anaerobic pond ranged from 7 to 20 over a range of loadings from 400 to 2250 lb/acre/day. For the facultative pond, the "odor products" increased from 1 to 9 as loadings increased from 150 to 500 lb/acre/day. Exceptions were an "odor product" of 8 at a loading of 50 lb/acre/day (run 9), and 9 at a loading of 230 lb/acre/day (run 11). In run 9, the "odor product" for the algae pond was 12 when the loading was 10 lb/acre/day. In all of the remaining runs the "odor product" for the algae pond was less than 5, and at one time only 1.

Effect of Recirculation

The "odor product" for the anaerobic pond ranged from 12 at a recirculation rate of 375,000 gal/min to 20 at no recirculation The only exceptions were in runs 5, 6 and 7, in which the product went up with increase in recirculation rate. However, it should be noted that these were the runs in which the partially treated pond waste waters were added to the algae pond. With respect to the algae and the facultative ponds, a slight increase in "odor product" accompanied increase in recirculation rate.

Effect of Series Arrangement

In Figure 42 (Appendix II), is indicated the relation of "odor product" to series arrangement. According to the figure, the odor product of the raw wastes ranged from 1 to 5. The greatest odor production was in the anaerobic pond, as is attested by its high odor product values, viz. 6 to 20. Odor production in the facultative pond as measured by "odor product" ranged from 1 to 9; and in the algae pond, with one exception, from 1 to 5.

pH

The effect on pH resulting from increasing the loading to the pond series is shown in Figure 43 (Appendix II). According to the figure, the pH of the influent liquid rose from a level between 6.0 to 7.0 (raw wastes) to 7.5 and 8.3. The average pH of the contents of the anaerobic pond was 7.2; of the facultative pond, 7.4; and of the algae pond 7.5 to 8.3.

Ancillary Experiments

Ancillary Studies

During the course of the study, small scale ancillary investigations were conducted to clarify problems that needed solution at the time. One was concerned with the effect of mixing and with determining the suitability of the flume water for growing algae; another with effect of three pesticides on algae predators; and a third with following the diurnal variation in the dissolved oxygen content of the aerobic pond.

Effect of Mixing

In this investigation, a miniature pond 8 ft X 16 ft X 1 ft was constructed on the levee of the anaerobic pond. The pond was filled with water from a nearby slough and was allowed to stand until an algal population developed. Experimental conditions and results obtained in the investigation are listed in Table 7. The information given in the table clearly demonstrated not only that mixing is essential to algae growth, but also that all of the nutrients needed for algal growth were present in the beet sugar flume water. It also showed that the addition of nutrients i.e., $(NH_4)_3PO_4$ and $Mg_3(PO_4)_2$, to the flume water had little, if any, effect on algae growth.

Table 7. - Effect of mixing on algal growth

OPERATIONS LOG

Detention time: 10 days
Feed source: anaerobic pond
Dimensions: 16 ft long, 8 ft wide, 1 foot deep
Pond lined with black plastic
Initial algae count: 5000 per cc

Date	Operation	Remarks
Jan. 10 - Jan. 23	No mixing: no feed	Algae count dropped to 0
Jan. 24 - Feb. 8	Feed: 80 gal/day; no mixing	Algae count dropped to 0
Feb. 9 - Feb. 28	Feed: 80 gal/day; mixing twice a day	Algae count increased to 2.2×10^6 per cc
Mar. 1 - Mar. 15	Feed: 80 gal/day; mixing twice a day	Factory effluent discharged in anaerobic pond. Algae count remained at 2.2×10^6 per cc

Table 7 (continued)

Mar. 23 - April 27	Same as previous run 5 ppm ammonium phosphate added daily	Algae count plateau: 1.5×10^6 per cc
April 28 - present	Feed: 80 gal/day; mixing twice a day 5 ppm magnesium phosphate added daily	Algae count plateau: 1.8×10^6 per cc

Use of Pesticides

The miniature pond described in the previous experiments was used in the sutdy. The pesticides Malathion, Lindane and Baytex were tested. Ammonium phosphate and magnesium nitrate also were tested on the possibility that they might exert an inhibitory influence on the growth of the predators.

In conducting the experiments, culture was transferred from the aerobic pond to the miniature pond. In runs in which the transferred culture was devoid of predators, predators were added. The latter were obtained from the aerobic pond.

Table 8. - Effect of pesticides on control of algae predators.

Biocide of Inhibitor		24 hr. kill	Remarks
Ammonium phosphate	1 ppm	0	No effect
	5 ppm	0	No effect
Magnesium nitrate	3 ppm	0	
	5 ppm	-	Daphnia and rotifers did not appear in sample
	5 ppm	0	Daphnia added to sample
Malathion	0.5 ppm	0	
	1.0 ppm	100%	
Lindane	0.25 ppm	100%	
	0.10 ppm	100%	
	0.08 ppm	80%	Total kill achieved in 48 hours
*Baytex	0.25 ppm	100%	Baytex will degrade in 72 hours

*Baytex: O-O Dimethyl O - 4 (Methylthio-m-tolyl) phosphorothioate 70.5%
Aromatic petroleum distillate 18.2%
Inert ingredients 11.3%

Experimental conditions and results are listed in Table 8. According to the results, the two nutritive compounds apparently

had no effect on predator survival. No kill was effected by Malathion at a dosage of 0.5 mg/l, whereas it was 100% effective at a dosage of 1.0 mg/l. Lindane was 100% effective at dosages from 0.08 mg/l to 0.25 mg/l. A 48-hour time period was necessary for accomplishing total kill at the lowest (0.08 mg/l) dosage. Baytex was 100% effective. Baytex has the advantageous characteristic of degrading within 72 hours.

Diurnal Variation in Dissolved Oxygen

The determination of the diurnal variation in dissolved oxygen concentration of the aerobic pond was made during the month of April. Unfortunately, the day on which the run was conducted was not an ideal one for oxygen production in as much as the temperature was low, some rain fell and the sky was overcast.

Experimental conditions and results are listed in Table 9. According to the table, the lowest dissolved oxygen concentration during the run was 10.4 mg/l; and the higest, 16.7. It is interesting to note that the dissolved oxygen concentration was at or above saturation throughout the entire 26-hour duration of the study.

Table 9. - Diurnal variation in dissolved oxygen.

Time of day	Water temp. ^{0}C.	Actual D.O.	*Saturation D.O.
10 a.m.	12.0	12.3	10.8
12 noon	12.8	15.0	10.6
2 p.m.	13.5	15.7	10.5
4 p.m.	14.0	16.5	10.4
8 p.m.	14.1	15.7	10.4
12 midnight	14.0	13.0	10.4
4 a.m.	11.2	11.1	11.1
8 a.m.	12.1	10.4	10.8
12 noon	13.0	12.8	10.6

*Chloride concentration in water assumed to be zero.
Sky cover: Overcast - dark clouds
Weather: Rain - showers during the day. Rained hard and steadily throughout the night.

X. DISCUSSION

The anaerobic-facultative-aerobic pond system as used in the study proved to be an extremely effective device for removing BOD, COD, volatile solids and nitrogen. However, most of the removal took place in the anaerobic pond. For example, 75% of the incoming total nitrogen was removed by passage through the anaerobic pond. Some of this initial loss may have been due to precipitation and settling out of colloidol and suspended

solids. Loss due to such phenomena probably would occur in any type of pond that was first in a series. However, the heavy loss of nitrogen in the anaerobic pond could have been a function of the anaerobic nature of the pond, since the loss by denitrification in any anaerobic situation can be quite extensive. The validity of these assumtions can only be proven by experimentation involving changes in the series arrangement of the ponds.

Several problems were encountered in operating the anaerobic-facultative-aerobic pond system, some of which can be explained in terms of shortcuts in pond design (i.e., of the aerobic pond), some in terms of the variations in method of operation necessitated in the conduct of research, and some in terms of inhibitory substances in the influent flume water. For example, a mixing system and its required equipment and structural components were not installed in the aerobic pond in the period covered by this report. Exigencies of time and budget as will as a desire to determine the feasibility of operating the pond series as a whole without it led to the omission of the mixing system. However, the absence of mixing undoubtedly contributed to the failure of algae to grow in any abundance in the aerobic pond (cf. "Ancillary Studies"), and hence to the lack of algae-produced oxygen in the pond contents. This in turn made recirculation ineffective as a method of oxygen input to the pond complex, and hence as a method of controlling odor.

Only one series arrangement was explored in the study, viz. anaerobic-facultative-aerobic. Perhaps another arrangement, as for example, aerobic-anaerobic-facultative, would result in a treatment superior to that attained in the present study, especially with respect to odor control. In the alternative arrangement given above, if the major reduction of BOD, COD, etc. would take place in the first pond, i.e., the aerobic pond, the first step as in the decomposition of the substances giving rise to these manifestations would be accomplished under aerobic conditions and hence would not be accompanied by the foul odors characteristic of anaerobic breakdown. Whether or not this would result in a lessening of odor production in the anaerobic pond can only be determined by experimentation. Another alternative in pond series arrangement would be the omission of the facultative pond. It is quite possible that the aerobic and the anaerobic ponds could adequately take over the function of the facultative pond, in effect functioning as a kind of phase separation. The aerobic pond would take over the function of the surface layer of the facultative pond, and the anaerobic pond, its lower or anaerobic layer.

During the course of the study, the need for or desirability of further investigation to find the answers to several questions became apparent. One of these pertains to natural and applied aeration. In this context, applied refers to aeration accomplished by physical means (mechanical aerators), and natural to that brought about by atmospheric diffusion and by algal activity. Preliminary studies indicated that decomposition can

be hastened and odors considerably diminished by superimposing applied aeration upon natural aeration. One problem is that of determining the extent of the gap between the amount of natural aeration available and that needed for optimum treatment, i.e., the amount of aeration that must be applied. Another is one of determining which is the best method of applying the aeration. A third aspect of the aeration question is one of determining and exploring methods of enhancing natural aeration.

The second question, the optimum sequence of ponds, has been touched upon earlier in the discussion.

The third concerns certain observations made in the present study. It is the matter of the apparently enhanced decomposition and waste treatment which occurred when the flume waters had a higher concentration of mud than they normally had. The enhancing effect may have been a function of increase in contact area, residue of inorganic fertilizer in the mud, or to the diffusion of growth factors (trace elements, vitamins, etc.) from the soil particles into the pond culture.

XI. SUMMARY AND CONCLUSIONS

1. It is not possible to operate an anaerobic pond without odor production unless the surface of the pond is aerated either by way of recirculation from an aerobic pond or by mechanical aeration.

2. In a pond series in which the arrangement is anaerobic pond-facultative pond-aerobic pond, the major part of the removal of BOD, COD, volatlle solids, coliforms and odor causing substances takes place in the anaerobic pond.

3. The effluent of the anaerobic pond, even under ideal operational conditions, is not suitable for discharge into the environment.

4. The following problems or questions should be explored:
   a) Extent of gap between the amount of available natural aeration and that which should be applied to obtain optimum treatment. Its corollaries: (1) the optimum method of supplying applied aeration; (2) methods for bringing about and for enhancing natural aeration.
   b) The arrangement of the pond series for accomplishing optimum treatment.
   c) Reasons for the apparent enhancement of the biological processes which occur when the soil content of the flume water is somewhat higher than normal.

5. The addition of fertilizer chemicals to the flume water had but little effect on algal growth.

6. Although sunlight and high (25^0C to 30^0C) temperatures are optimum environmental conditions for algae production, at

no time were light and temperature at a level at which the algae production was less than that needed for waste treatment.

7. In a 26-hour period of observation, the dissolved oxygen concentration of the aerobic pond remained at or above saturation, despite the fact that environmental conditions were unfavorable for algal activity.

8. Mixing is essential for production and maintenance of the algal population required for maximum efficiency of flume-water treatment in a pond series of the type used in the study.

9. Odor production:
   a) Odor production increased in the anaerobic pond with an increase in BOD loading. It generally was low in the facultative and aerobic ponds at all of the loadings applied.
   b) Increase in recirculation rate brought about a reduction in odor production in the anaerobic pond. No significant effect of recirculation rate or odor production by the facultative and algae ponds was noted.

no time were light and temperature at a level at which the algae production was less than that needed for waste treatment.

7. In a 26-hour period of observation, the dissolved oxygen concentration of the aerobic pond remained at or above saturation, despite the fact that environmental conditions were unfavorable for algal activity.

8. Mixing is essential for production and maintenance of the algal population required for maximum efficiency of flume-water treatment in a pond series of the type used in the study.

9. Odor production:
   a) Odor production increased in the anaerobic pond with an increase in BOD loading. It generally was low in the facultative and aerobic ponds at all of the loadings applied.
   b) Increase in recirculation rate brought about a reduction in odor production in the anaerobic pond. No significant effect of recirculation rate or odor production by the facultative and algae ponds was noted.

Appendix I

Tables

Table 1. - Card layout for Monday, Wednesday, Friday observations

Columns	Observations	Units	Remarks
1 - 8	Date		
10 - 14	Biochemical Oxygen Demand	ppm	* Space Blank
16 - 19	Unfiltered Chemical Oxygen Demand	ppm	
21 - 24	Filtered Chemical Oxygen Demand	ppm	
26 - 29	Dissolved Oxygen	ppm	
31 - 35	Algae Counts	cm_3	E+XX represents the power of 10 which the characteristic must be raised to obtain true value.
37 - 40	Carbon Dioxide	ppm %	Gas Analysis
42 - 45	Oxygen	ppm %	Gas Analysis
47 - 50	Carbon Monoxide	ppm %	Gas Analysis
52 - 55	Hydrogen	ppm %	Gas Analysis
57 - 60	Methane	ppm %	Gas Analysis
62 - 65	Nitrogen	ppm %	Gas Analysis
66 - 78	Blank		
79	Card Code	M - Monday, Wednesday, Friday	
80	Station Code		

Table 2. - Card layout of physical observations

Columns	Observations	Units	Remarks
1 - 6	Date		The date is recorded month-day-year
7 - 10	Influent Temperature	°C	Color is coded as follows A - Black 1 - Faint B - Pink 2 - Light C - Green 3 - Medium D - Brown 4 - Medium Dark 5 - Dark
11 - 12	Influent Color-Intensity		
13 - 14	Influent Odor-Intensity		
15 - 17	Influent Flow Measure	gpm	
18 - 24	Solar Reading	Amp hrs.	Odor is coded as follows 0 - None F - Foul 1 - Faint H - H_2S 2 - Light C - Cow Dung 3 - Medium B - Beety 4 - Medium Strong O - Other 5 - Strong
25	Sky Cover		
26	Wind Velocity		
28 - 30	Anaerobic Evaporation	in./day	Sky Cover is coded as follows Cloudy - C Hazy - H Clear - L Fog - F
31 - 32	Anaerobic Top temperature	°C	
33 - 34	Anaerobic Bottom temperature	°C	
35 - 36	Anaerobic Color-Intensity		
37 - 38	Anaerobic Odor-Intensity		Wind is coded as follows Strong - S Mild - M Breeze - B None - 0
39 - 41	Anaerobic Flow Measure	gpm	
43 - 45	Facultative Evaporation	in./day	* Space Blank
46 - 47	Facultative Top temperature	°C	
48 - 49	Facultative Bottom temperature	°C	
50 - 51	Facultative Color-Intensity		
52 - 53	Facultative Odor-Intensity		
54 - 56	Facultative Flow Measure	gpm	
58 - 60	Algae Evaporation	in./day	
61 - 62	Algae Top temperature	°C	
63 - 64	Algae Bottom temperature	°C	
65 - 66	Algae Color-Intensity		
67 - 68	Algae Odor-Intensity		
69 - 71	Algae Flow Measure	gpm	
72 - 79	Blank		
80	P - Physical		

Table 3. - Card layout of daily observations.

Columns	Observations	Units	Remarks
1 - 8	Date		* Space Blank
10 - 13	Volumetric Solids-Total	ppm	
15 - 16	Volumetric Solids-% Algae	ppm	
18 - 21	Dissolved Total Solids	ppm	
22 - 25	Dissolved Ash	ppm	
26 - 29	Dissolved Volatile	ppm	
31 - 34	Total Suspended Solids	ppm	
35 - 38	Suspended Ash	ppm	
39 - 42	Suspended Volatile	ppm	
44 - 47	Total Solids	ppm	
48 - 51	Total Ash	ppm	
52 - 55	Total Volatile	ppm	
57 - 60	pH Factor		
62 - 64	Conductivity X 1	Millivolts	
66 - 68	Light Penetration	mm.	
70 - 71	% Sugar Content	%	
72 - 78	Blank		
79	Card Code	Daily	
80	Station Code		

Table 4. - Card layout for Tuesday, Thursday, Saturday observations.

Columns	Observations	Units	Remarks
1 - 8	Date		
10 - 14	Total Nitrogen	ppm	* Space Blank
16 - 19	Ammonia Nitrogen	ppm	
21 - 24	Nitrate	ppm	
26 - 30	Sulfate	ppm	Sulfate test done with silica removal
32 - 35	Sulfide	ppm	
37 - 40	Phosphate	ppm	
42 - 46	Calcium	ppm	
48 - 52	Magnesium	ppm	
54 - 59	Algae Counts	cm^3	E+XX represents the power of 10 which the characteristic must be raised to obtain true value.
79	Card Code	T - Tuesday, Thursday, Saturday	
80	Station Code		

Table 5. Indicator microorganism data. Coliform, fecal coliform and fecal streptococci data: Fall 1966.

Date	Micro-organisms	Sample station MPN per 100 ml						
		A	B	C	I	II	III	IV
3/10/66	Coliform	15×10^{4}	24×10^{6}	$<10^{4}$	11×10^{9}	21×10^{3}	43×10^{3}	43×10^{2}
	Fecal coli.	40×10^{2}	40×10^{4}	$<10^{4}$	23×10^{7}	40×10^{2}	23×10^{2}	40×10^{1}
	Fecal strep.	43×10^{5}	$>10^{8}$	24×10^{8}	11×10^{7}	43×10^{4}	43×10^{3}	43×10^{2}
9/19/66	Coliform	$<10^{4}$	$>10^{8}$	43×10^{5}	24×10^{8}	21×10^{4}	23×10^{3}	43×10^{2}
	Fecal coli.	$<10^{4}$	$<10^{4}$	15×10^{5}	43×10^{4}	23×10^{2}	23×10^{2}	90×10^{1}
	Fecal strep.	75×10^{7}	$>10^{8}$	20×10^{5}	11×10^{8}	15×10^{5}	90×10^{3}	23×10^{2}
9/26/66	Coliform	$<10^{4}$	28×10^{7}	43×10^{6}	$>10^{5}$	11×10^{6}	93×10^{4}	15×10^{3}
	Fecal coli.	$<10^{4}$	20×10^{7}	43×10^{6}	$>10^{5}$	43×10^{3}	23×10^{3}	93×10^{2}
	Fecal strep.	$<10^{4}$	46×10^{7}	70×10^{5}	$>10^{5}$	15×10^{5}	21×10^{3}	$>10^{5}$
10/10/66	Coliform	43×10^{3}	93×10^{7}	21×10^{6}	24×10^{5}	93×10^{5}	24×10^{3}	23×10^{2}
	Fecal coli.	23×10^{3}	15×10^{5}	90×10^{4}	24×10^{5}	$<10^{2}$	93×10^{2}	90×10^{1}
	Fecal strep.	15×10^{4}	11×10^{9}	11×10^{9}	$>10^{8}$	43×10^{5}	93×10^{3}	23×10^{3}
10/17/66	Coliform	21×10^{3}	23×10^{7}	15×10^{6}	21×10^{8}	15×10^{5}	90×10^{3}	23×10^{3}
	Fecal coli.	23×10^{2}	15×10^{6}	15×10^{6}	20×10^{7}	90×10^{3}	15×10^{3}	23×10^{2}
	Fecal strep.	93×10^{2}	93×10^{8}	43×10^{5}	21×10^{8}	43×10^{5}	93×10^{3}	43×10^{2}

Table 6. - Coliform, fecal coliform and fecal streptococci data: Spring 1967.

Date	Micro-organisms	Sample station MPN per 100 ml						
		A	B	C	I	II	III	IV
4/ 3/67	Coliform	$93x10^3$	$93x10^6$	$43x10^5$	$93x10^6$	$93x10^4$	$93x10^2$	$23x10^1$
	Fecal coli.	$23x10^2$	$36x10^5$	$93x10^4$	$90x10^4$	$23x10^3$	$23x10^2$	<23
	Fecal strep.	$43x10^2$	$93x10^5$	$43x10^4$	$43x10^5$	$93x10^2$	$36x10^1$	<23
4/10/67	Coliform	$24x10^4$	-	$43x10^6$	-	$15x10^4$	$75x10^3$	$23x10^1$
	Fecal coli.	$40x10^2$	-	$15x10^6$	-	$75x10^3$	$43x10^1$	40
	Fecal strep.	$23x10^1$	-	$23x10^5$	-	$90x10^2$	40	40
5/ 1/67	Coliform	$43x10^4$	$93x10^5$	$43x10^5$	$23x10^7$	$<10^2$	$<10^2$	$<10^2$
	Fecal coli.	$93x10^2$	$23x10^4$	$23x10^5$	$43x10^4$	$<10^2$	$<10^2$	$<10^2$
	Fecal strep.	$40x10^1$	$43x10^5$	$23x10^5$	$23x10^6$	$<10^2$	$<10^2$	$<10^2$
5/ 8/67	Coliform	$43x10^3$	$93x10^6$	-	$43x10^7$	$43x10^4$	$23x10^3$	$90x10^1$
	Fecal coli.	$40x10^2$	$93x10^4$	-	$93x10^6$	$23x10^4$	$90x10^1$	$<10^2$
	Fecal strep.	$<10^2$	$43x10^6$	-	$30x10^3$	$40x10^1$	$40x10^1$	$<10^2$
5/15/67	Coliform	$93x10^4$	$43x10^6$	$93x10^4$	-	$23x10^4$	$64x10^3$	$23x10^2$
	Fecal coli.	$<10^2$	$23x10^5$	$93x10^4$	-	$43x10^3$	$23x10^3$	$43x10^1$
	Fecal strep.	$23x10^2$	$93x10^4$	$43x10^4$	-	$43x10^2$	$93x10^1$	$<10^2$
5/22/67	Coliform	$43x10^4$	$23x10^7$	$93x10^6$	$93x10^6$	$43x10^5$	-	$12x10^2$
	Fecal coli.	$43x10^2$	$11x10^5$	$43x10^6$	$93x10^5$	$43x10^4$	$43x10^1$	-
	Fecal strep.	$23x10^2$	$75x10^5$	$23x10^4$	$93x10^4$	$93x10^3$	-	-
5/29/67	Coliform	$43x10^4$	$93x10^5$	$39x10^5$	$43x10^7$	$43x10^6$	-	$43x10^4$
	Fecal coli.	$43x10^2$	$23x10^5$	$93x10^4$	$21x10^6$	$93x10^4$	$21x10^4$	$21x10^3$
	Fecal strep.	-	$93x10^5$	$93x10^5$	$23x10^5$	-	$23x10^2$	$43x10^1$
6/ 5/67	Coliform	$43x10^4$	$23x10^6$	$75x10^5$	$43x10^6$	$43x10^5$	$23x10^4$	$39x10^3$
	Fecal coli.	-	$93x10^4$	$43x10^5$	$15x10^6$	-	$93x10^3$	$43x10^2$
	Fecal strep.	-	$43x10^4$	$43x10^4$	$23x10^5$	-	-	-
6/12/67	Coliform	$23x10^4$	$23x10^6$	$75x10^5$	$43x10^6$	$43x10^5$	$23x10^4$	$23x10^3$
	Fecal coli.	$23x10^2$	$93x10^4$	$43x10^5$	$15x10^6$	$23x10^4$	$93x10^3$	$43x10^2$
	Fecal strep.	$23x10^1$	$43x10^4$	$43x10^4$	$23x10^5$	$23x10^3$	$23x10^2$	$23x10^1$

Table 7. - Algae counts in the facultative and anaerobic ponds.

Run #	Date Mo-Day-Yr	Feed rate gal x 10^3 per day	Recir. rate gal x 10^3 per day	Light energy BTU x 10^3 ft^2/amp hr	Facultative pond cells x $10^3/cm^3$	Algae pond cells x $10^3/cm^3$
6	10-20-66	100	50	-	-	15.0
	24			-	20.0	120.0
	26			-	124.5	116.3
	28			-	60.0	70.0
	31			-	70.0	55.0
	11- 1-66			-	50.0	40.0
	2			-	50.0	30.0
	4			-	25.0	40.6
	7			-	7.5	10.0
7	11-11-66	144	0	-	2.5	12.5
	14			-	5.0	10.0
	15			-	2.5	10.0
	16			-	5.0	5.0
	18			-	2.5	5.0
	21			-	0	17.5
	22			-	2.5	20.0
	23			-	10.0	25.0
Fac-	25			-	2.5	5.0
tory	26			-	5.0	10.0
down	28			-	7.5	12.5
	29			-	10.0	15.0
	30			-	5.0	18.75
	12-30-66			-	52.5	0
	1- 9-67			-	2.5	2.5
	30			-	0	2.5
	2- 6-67			-	0	2.5
	7			-	0	5.0
	9			-	2.5	2.5
	10			-	0	2.5
	22			-	2.5	2.5
	28			-	2.25	11.25
	28			-	22.5	52.5
8	3- 1-67	150	0	-	40.0	85.0
	2			-	40.0	60.0
	3			-	20.0	80.0
	4			-	10.0	70.0
	6			-	40.0	310.0
	7			-	12.5	250.0
	8			-	0	307.5
	9			-	17.5	530.0
	11			-	-	120.0
	13			-	2.5	85.0

Table 7. (continued)

Run #	Date Mo-Day-Yr	Feed rate gal x 10^3 per day	Recir. rate gal x 10^3 per day	Light energy BTU x 10^3 ft^2/amp hr	Facultative pond cells x $10^3/cm^3$	Algae pond cells x $10^3/cm^3$
8	3-14-67	150	0	-	-	225.0
	15			-	7.5	400.0
Factory down	16			-	5.0	267.5
	17			-	-	280.0
	20			-	0	562.5
	21			-	-	425.0
	22			-	-	425.0
	23			-	0	100.0
	24			-	-	375.0
	25			-	-	625.0
	27			-	2.5	950.0
	28			-	-	1,032.5
	29			-	-	687.0
	30			-	-	1,115.0
	31			-	20.0	1,170.0
	4- 3-67			-	90.0	1,145.0
	4			-	15.0	1,140.0
	5			-	20.0	1,191.5
	6			-	22.5	-
	11			-	20.0	500.0
9	5- 1-67	50	58	259.0	610.0	700.0
	2			259.0	367.5	420.0
	3			201.0	487.5	615.0
	4			196.7	600.0	675.0
	5			196.0	575.0	685.0
	6			201.0	700.0	880.0
	7			184.8	125.0	1,017.0
	8			184.8	70.0	1,250.0
	9			197.4	47.2	970.0
	10			102.9	40.0	930.0
	11			192.5	150.0	512.5
	12			242.9	52.0	535.0
	15			-	70.0	785.0
	16			-	110.0	343.0
	17			-	25.0	757.5
	18			-	42.5	770.0
	19			-	50.0	875.0
	20			-	80.0	887.5
	22			-	295.0	847.5
10	5-23-67	260	260	-	35.0	917.5
	24			-	25.0	737.5
	25			-	25.0	1,052.0
	26			-	20.0	1,052.0
	27			-	-	1,052.0

Table 7. (continued)

Run #	Date Mo-Day-Yr	Feed rate gal x 10^3 per day	Recir. rate gal x 10^3 per day	Light energy BTU x 10^3 ft^2/amp hr	Facultative pond cells x $10^3/cm^3$	Algae pond cells x $10^3/cm^3$
10	5-29-67	260	260	-	-	1,117.5
	30			-	-	1,350.0
	31			-	-	1,380.0
	6- 1-67			-	-	1,242.5
	2			-	-	1,250.0
	3			-	-	882.5
	5			-	-	1,290.0
	6			-	-	1,345.0
	7			-	-	1,380.0
	8			-	-	1,400.0
	9			-	-	1,286.0
	10			-	-	1,540.5
	12			-	-	1,530.0
	13			-	-	1,675.0
	14			-	-	852.0
	15			-	-	875.0
	16			-	-	895.0
	17			-	-	696.0
	19			-	-	510.0
	20			-	-	515.0

Table 8. - Results of sulfate and sulfide analyses in the pond series.

SULFATE

Run #	Influent	Anaerobic	Facultative	Algae
5	567.0	17.3	20.6	26.4
6	377.0	87.4	78.3	102.2
7	-	-	-	-
8	432.0	115.0	55.3	46.2
9	150.0	64.0	70.8	70.5
10	835.0	158.0	97.2	112.0
11	607.0	64.3	44.4	74.0

SULFIDE

Run #	Influent	Anaerobic	Facultative	Algae
5	0.36	1.20	0.05	0.00
6	0.60	4.40	0.20	0.00
7	0.00	2.00	0.36	0.10
8	0.00	0.10	0.00	0.00
9	0.25	2.03	0.00	0.00
10	3.10	5.20	0.49	0.00
11	0.67	2.77	0.74	0.18

Appendix II

Figures

40 A

Figure 1. - Aerial view of pilot plant - commercial lagoons upper right.

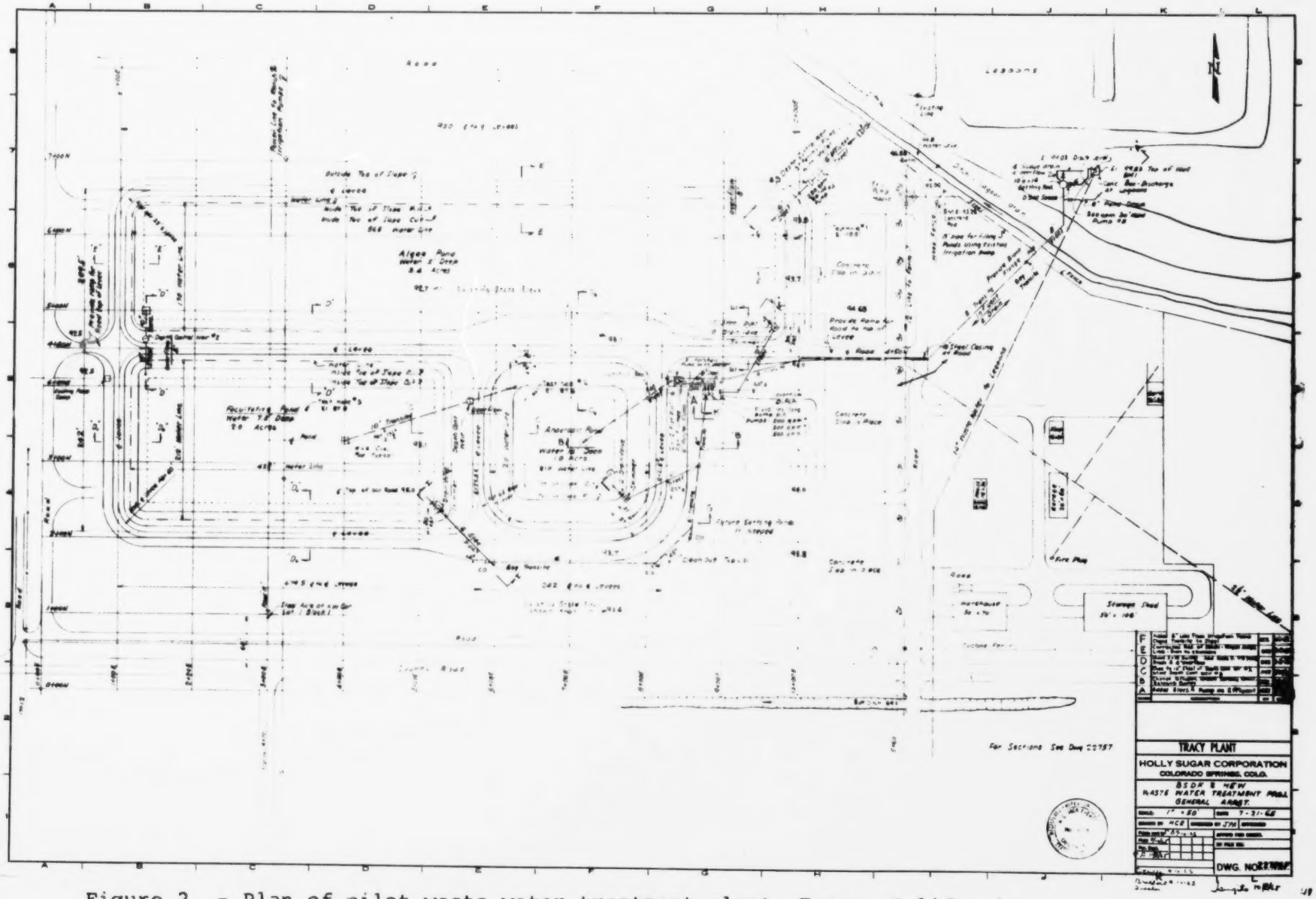

Figure 2. - Plan of pilot waste water treatment plant, Tracy, California.

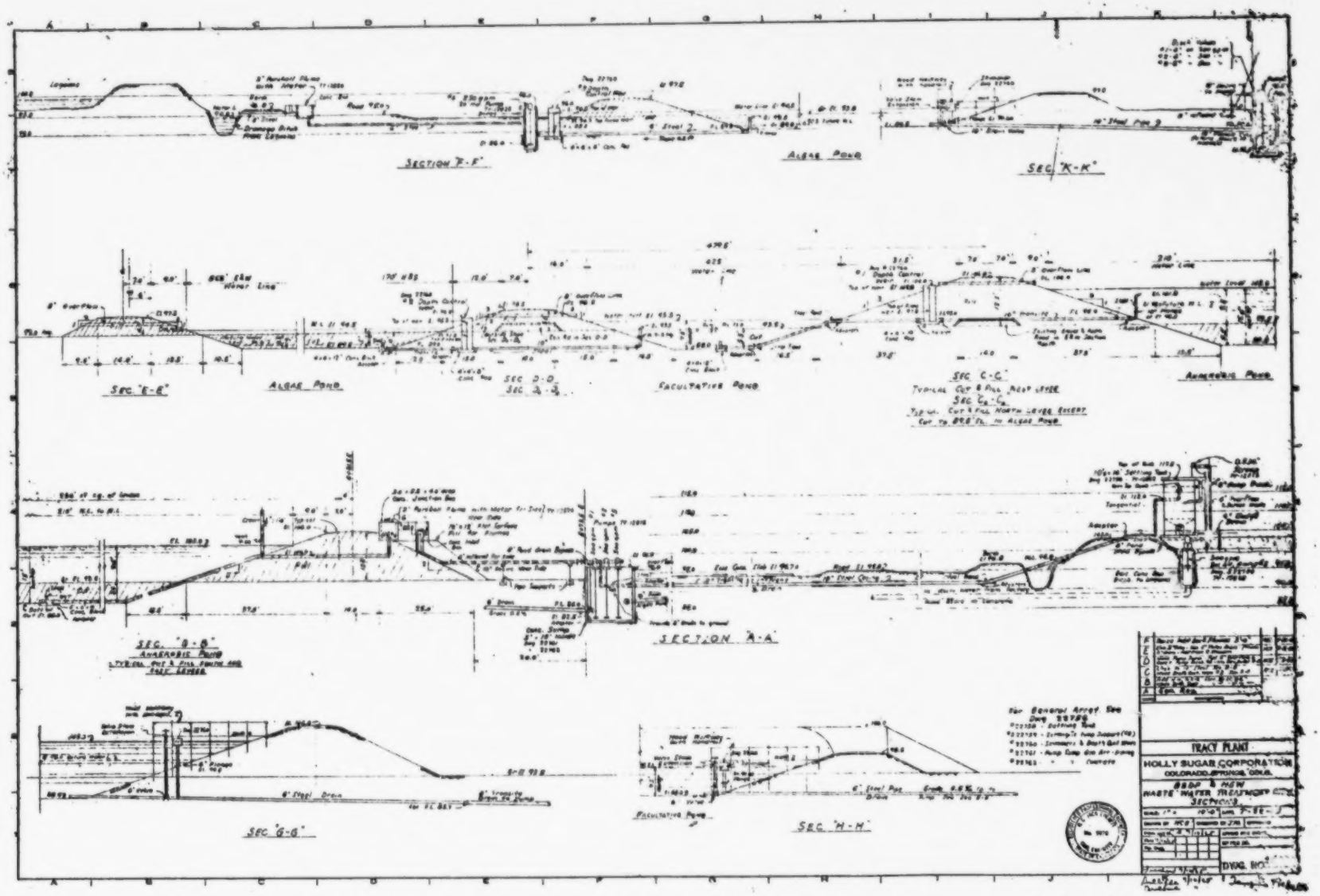

Figure 3. - Sections of pilot waste water treatment plant, Tracy, California.

Reproduced from best available copy.

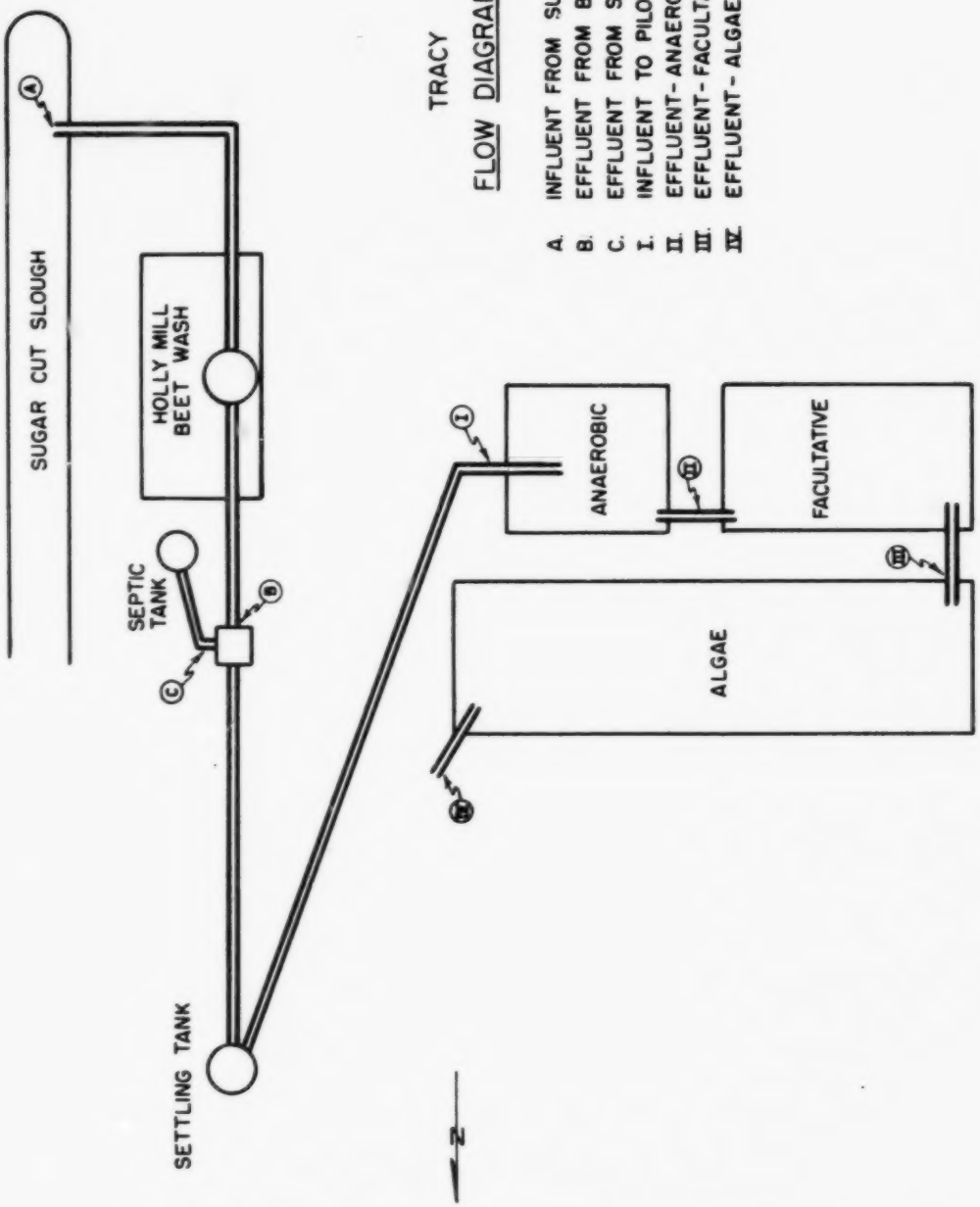

Figure 4. - Schematic flow diagram showing seven primary sampling points.

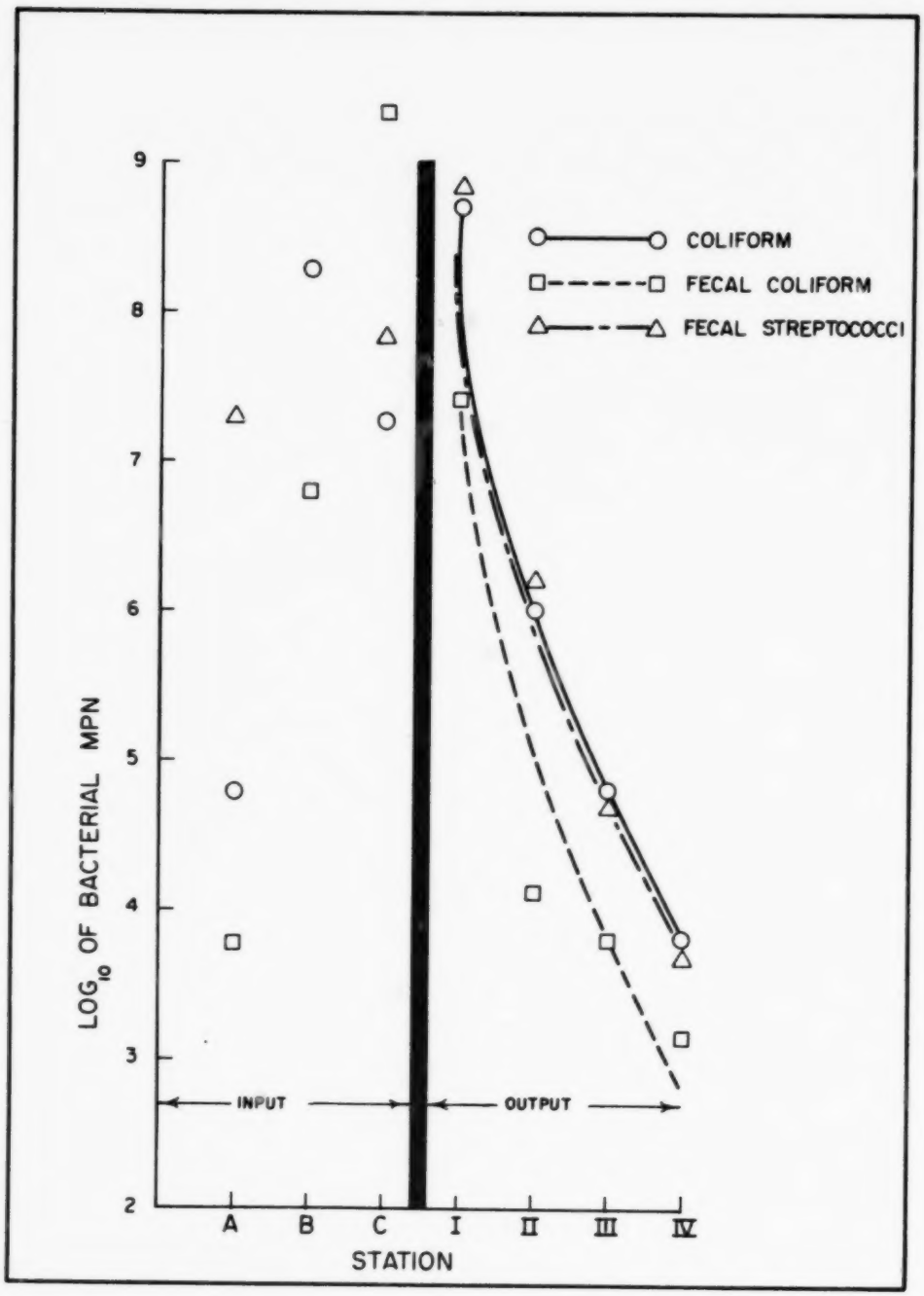

Figure 5. - Reduction of bacterial MPN at the sampling stations, fall of 1966.

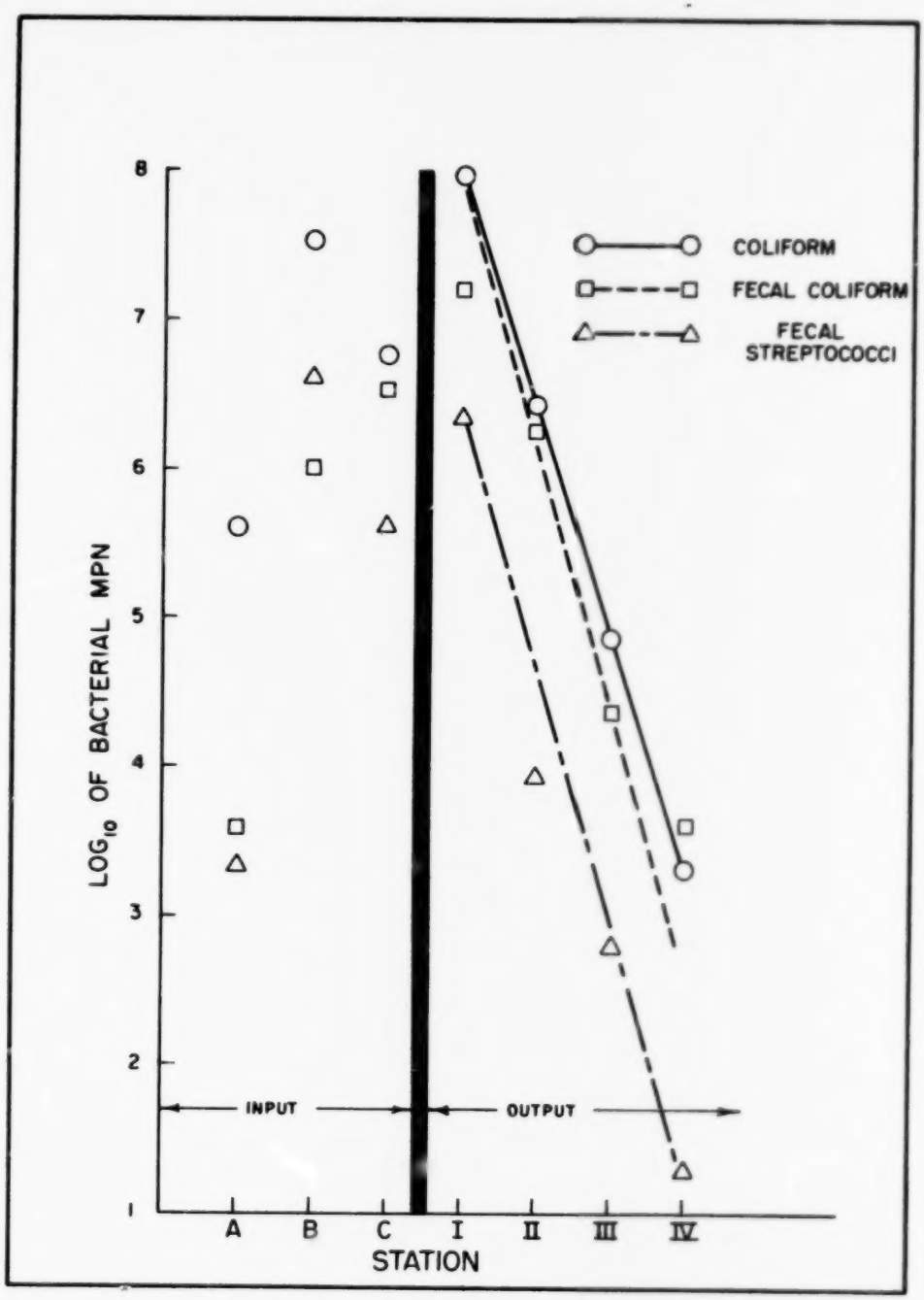

Figure 6. - Reduction of bacterial MPN at the sampling stations, spring of 1967. (Analyses performed at the University of California, Berkeley).

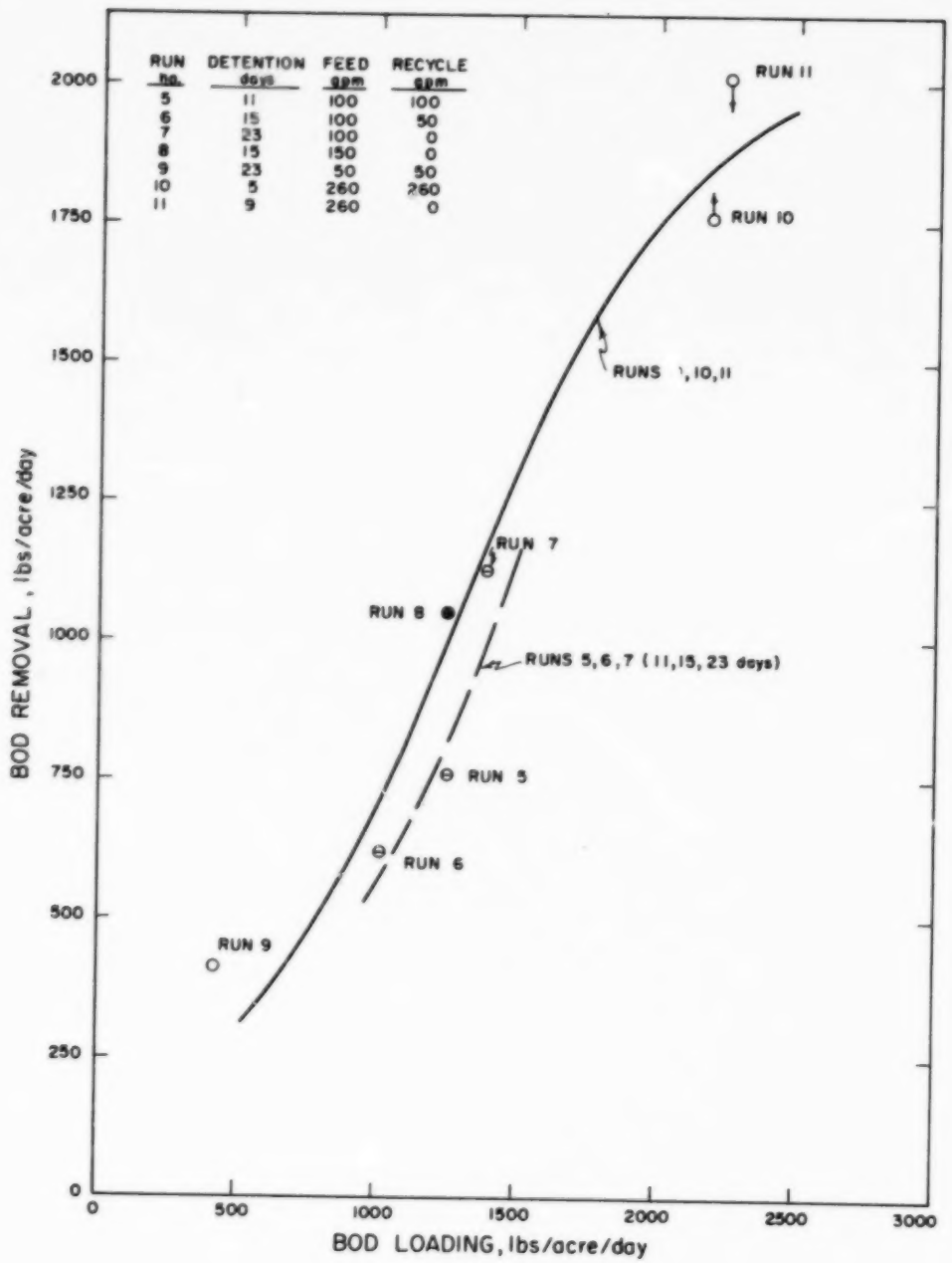

Figure 7. - The influence of loading on BOD removal in the anaerobic pond.

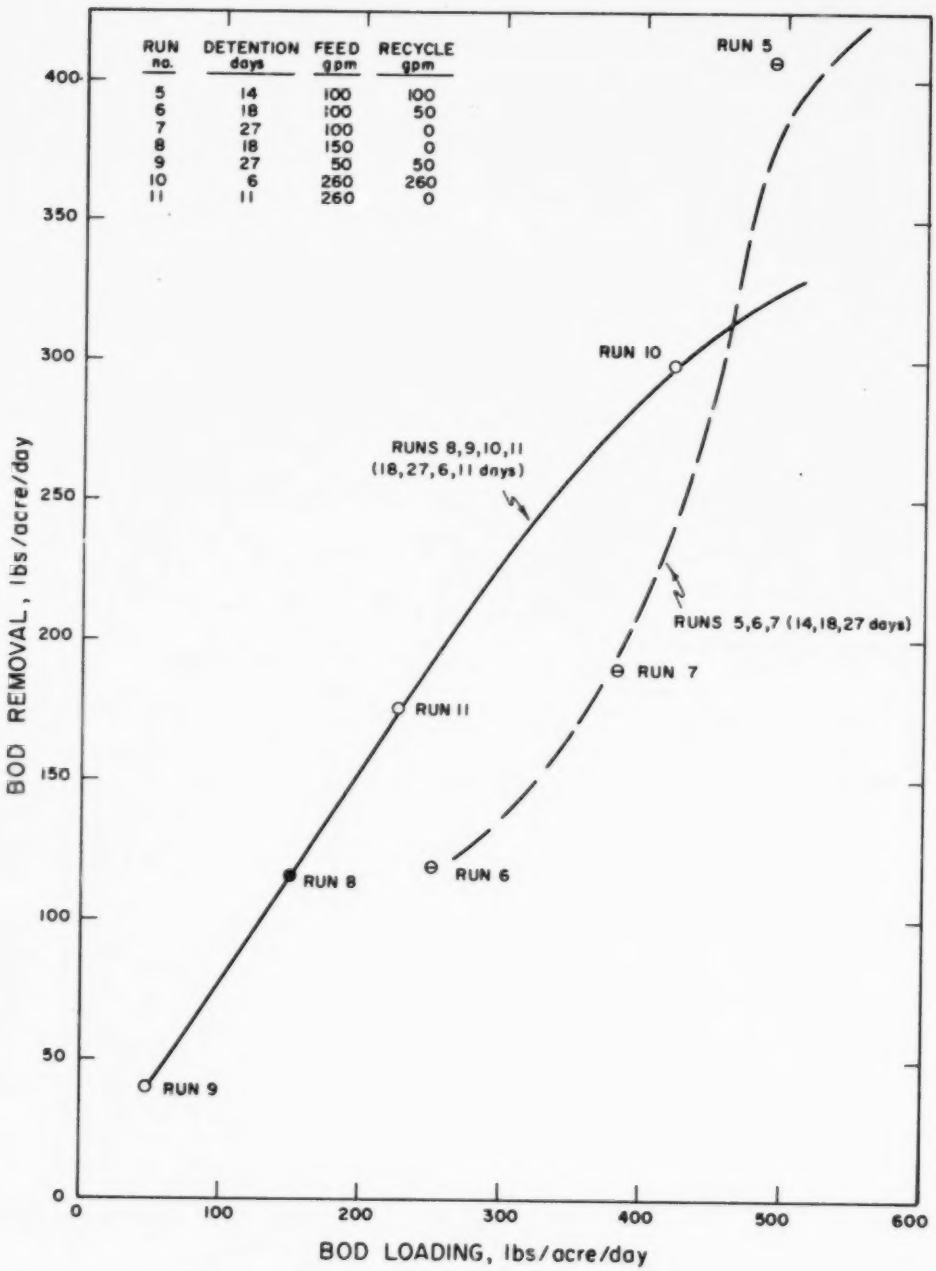

Figure 8. - The influence of loading on BOD removal in the facultative pond.

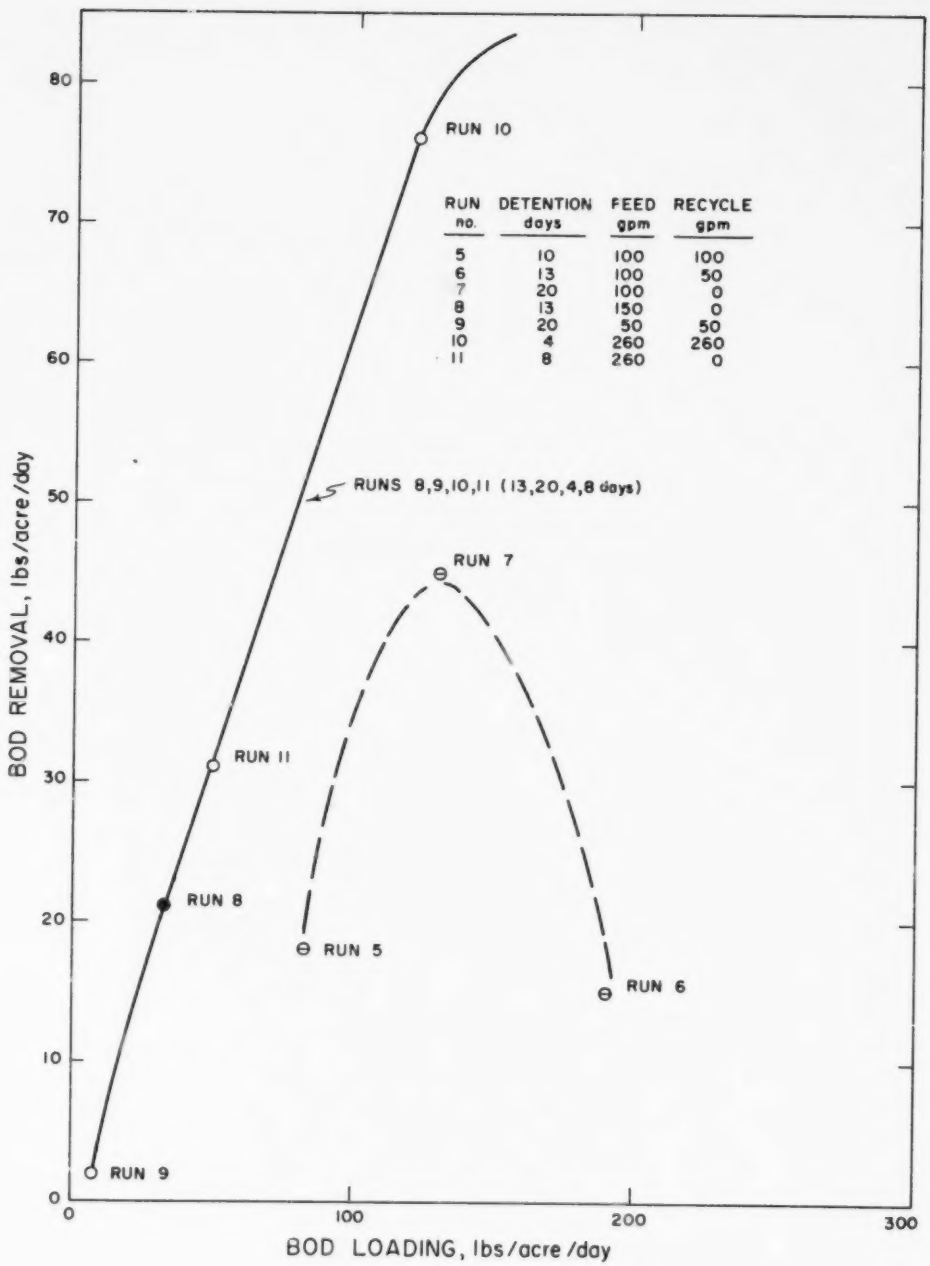

Figure 9. - The influence of loading on BOD removal in the aerobic pond.

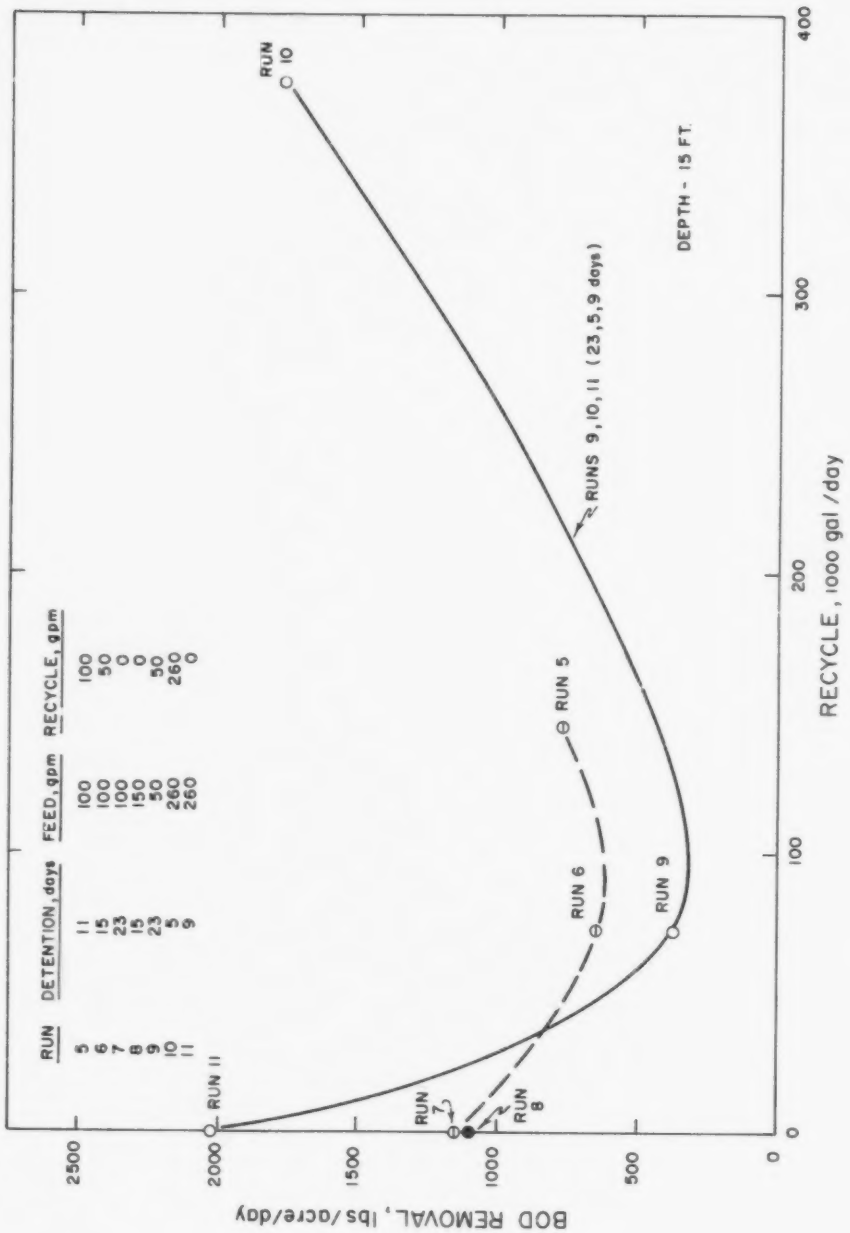
BOD REMOVAL, lbs/acre/day
RECYCLE, 1000 gal/day
DEPTH - 15 FT.
RUNS 9, 10, 11 (23,5,9 days)
RUN 10
RUN 5
RUN 6
RUN 9
RUN 11
RUN 7
RUN 8
RUN | DETENTION, days | FEED, gpm | RECYCLE, gpm
5 | 11 | 100 | 100
6 | 15 | 100 | 50
7 | 23 | 100 | 0
8 | 15 | 150 | 0
9 | 23 | 50 | 50
10 | 5 | 260 | 260
11 | 9 | 260 | 0

Figure 10. - The influence of recirculation on BOD removal in the anaerobic pond.

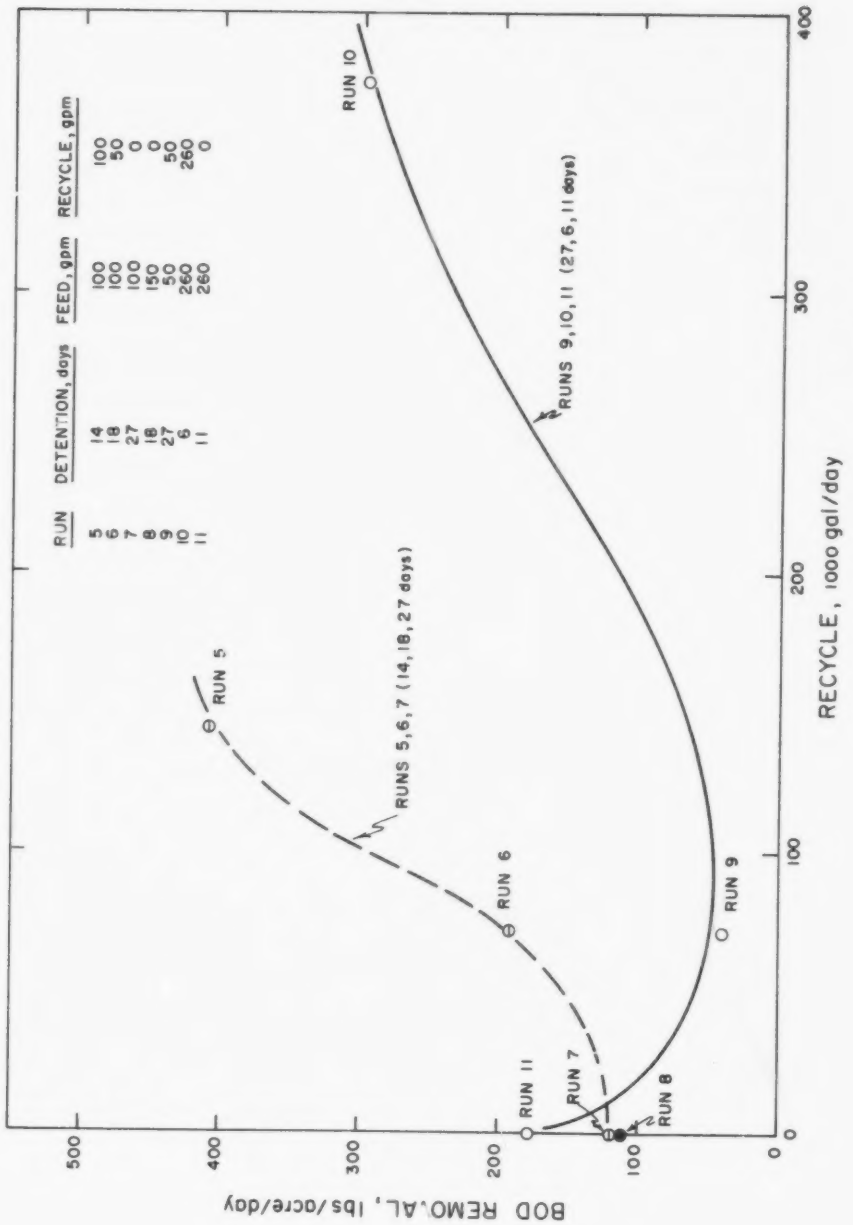

Figure 11. - The influence of recirculation on BOD removal in the facultative pond.

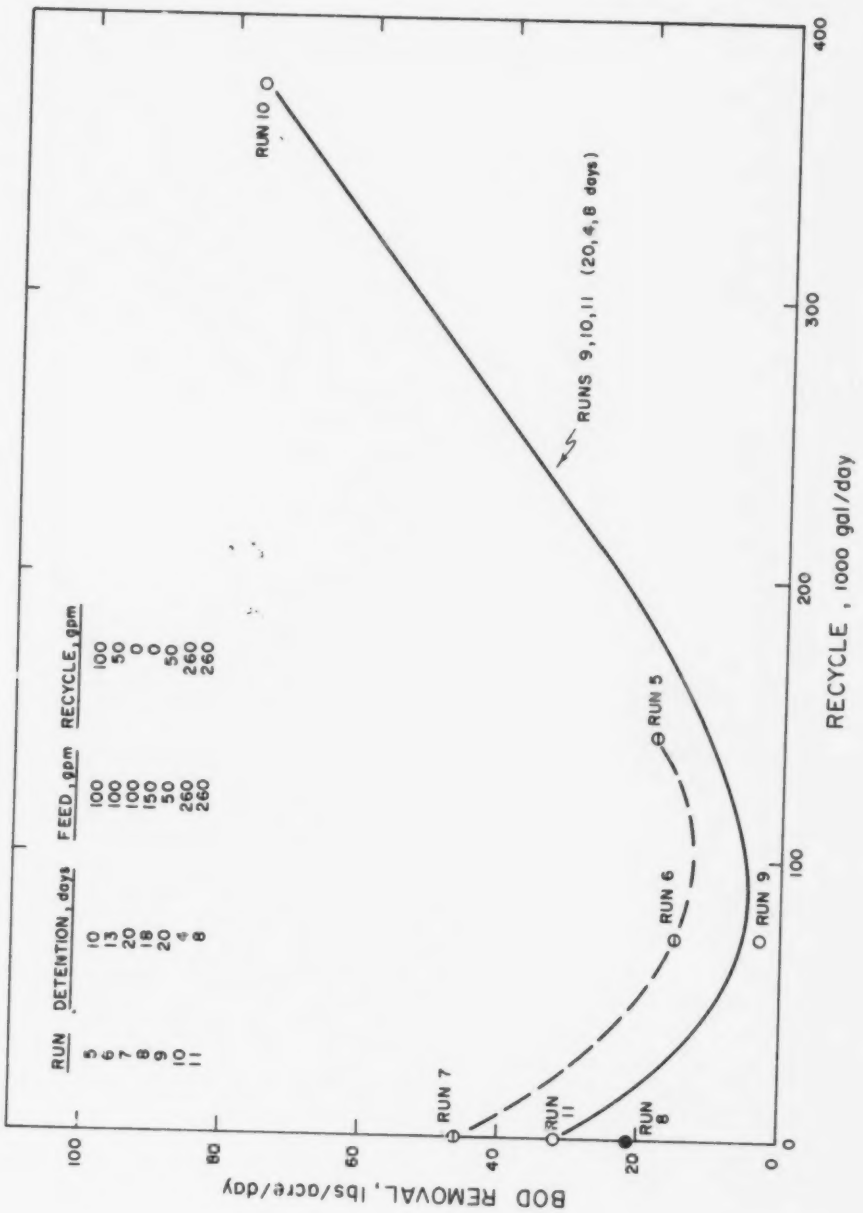

Figure 12. - The influence of recirculation on BOD removal in the aerobic pond.

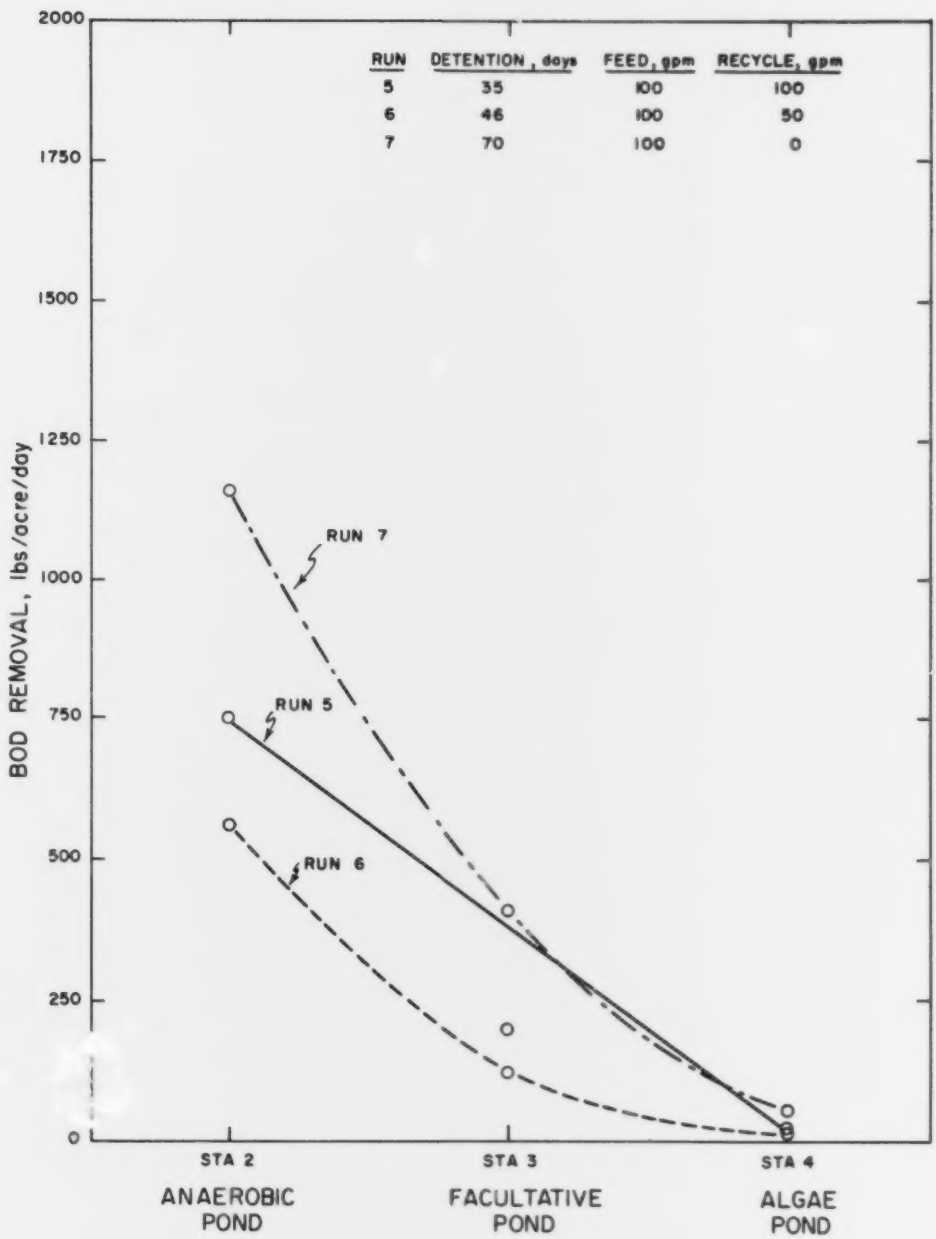

Figure 13A. - Effect of the anaerobic, facultative, aerobic series treatment on BOD removal for runs 5, 6 and 7.

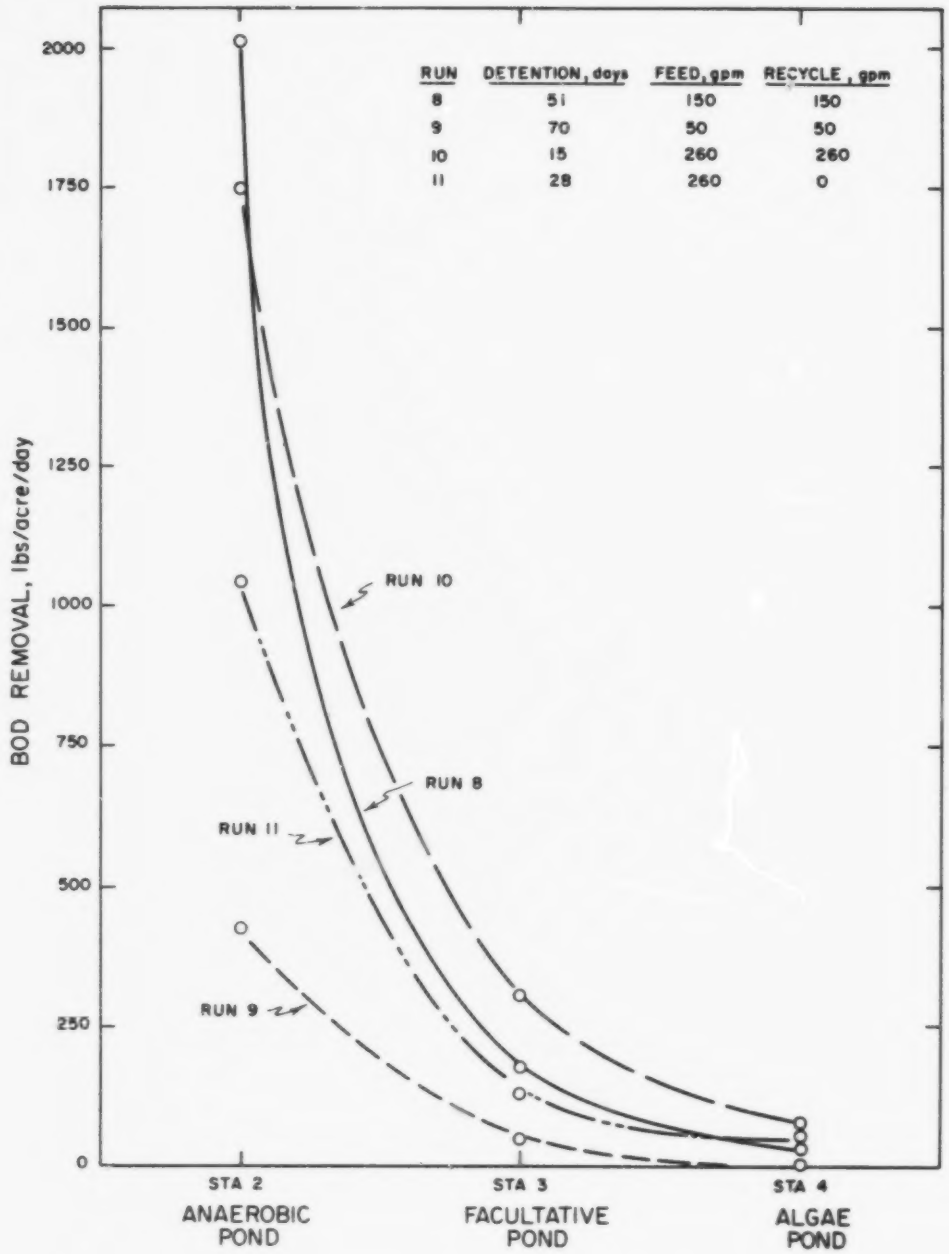

Figure 13B. - Effect of the anaerobic, facultative, aerobic series treatment on BOD removal for runs 8, 9, 10 and 11.

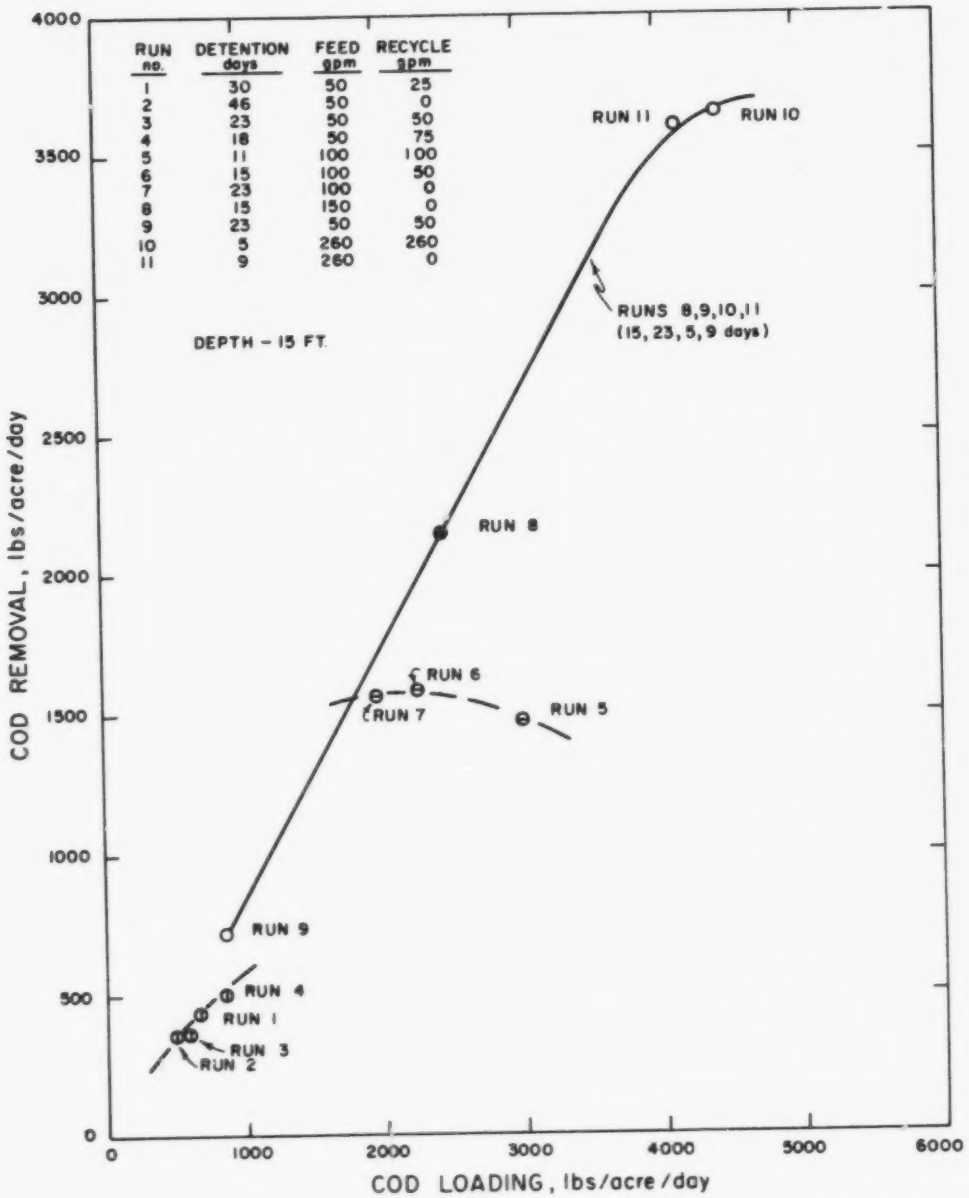

Figure 14. - The influence of loading on COD removal in the anaerobic pond.

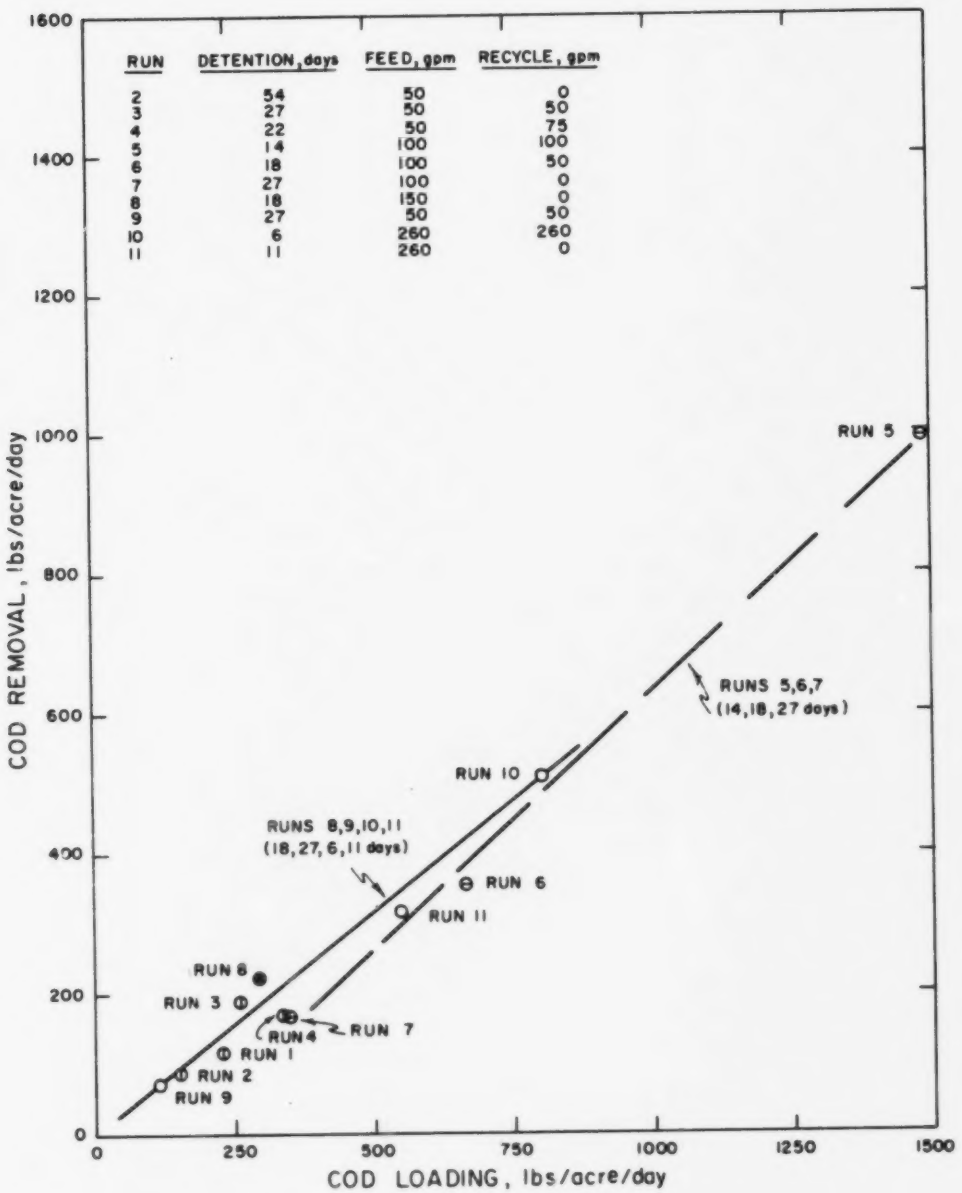

Figure 15. - The influence of loading on COD removal in the facultative pond.

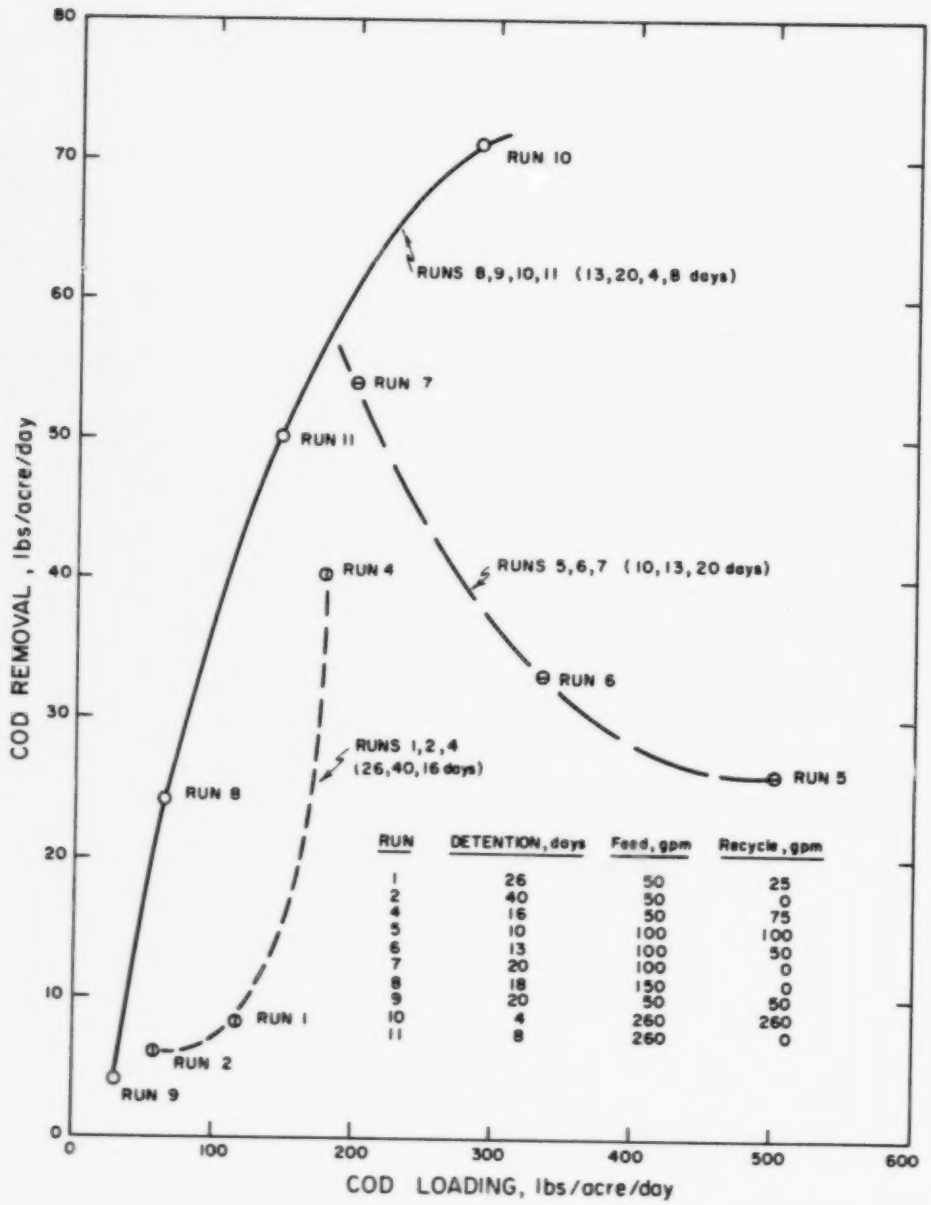

Figure 16. - The influence of loading on COD removal in the aerobic pond.

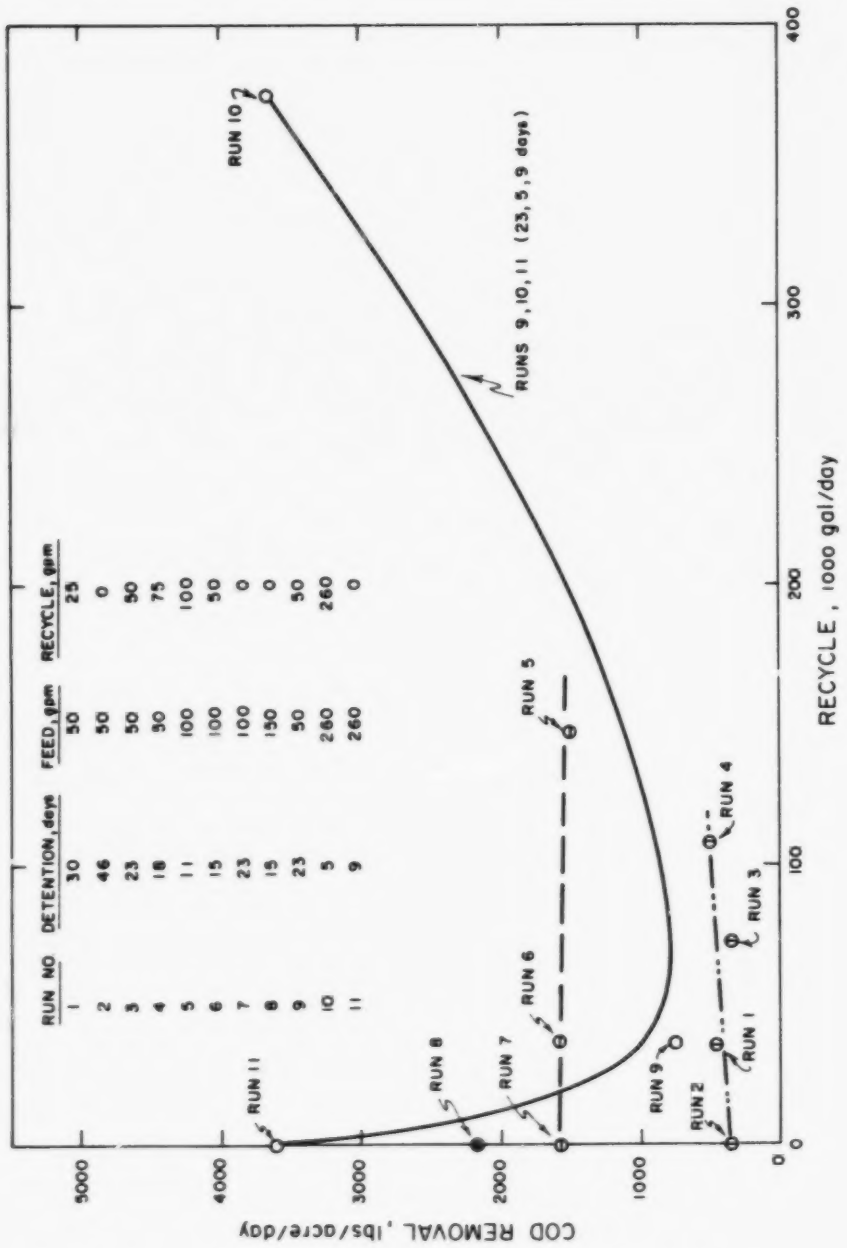
COD REMOVAL, lbs/acre/day
RECYCLE, 1000 gal/day
RUN NO | DETENTION, days | FEED, gpm | RECYCLE, gpm
1 | 30 | 50 | 25
2 | 46 | 50 | 0
3 | 23 | 50 | 50
4 | 18 | 50 | 75
5 | 11 | 100 | 100
6 | 15 | 100 | 50
7 | 23 | 100 | 0
8 | 15 | 150 | 0
9 | 23 | 50 | 50
10 | 5 | 260 | 260
11 | 9 | 260 | 0
RUN 10
RUNS 9, 10, 11 (23, 5, 9 days)
RUN 11
RUN 8
RUN 7
RUN 6
RUN 5
RUN 4
RUN 3
RUN 2
RUN 1
RUN 9

Figure 17. - The influence of recirculation on COD removal in the anaerobic pond.

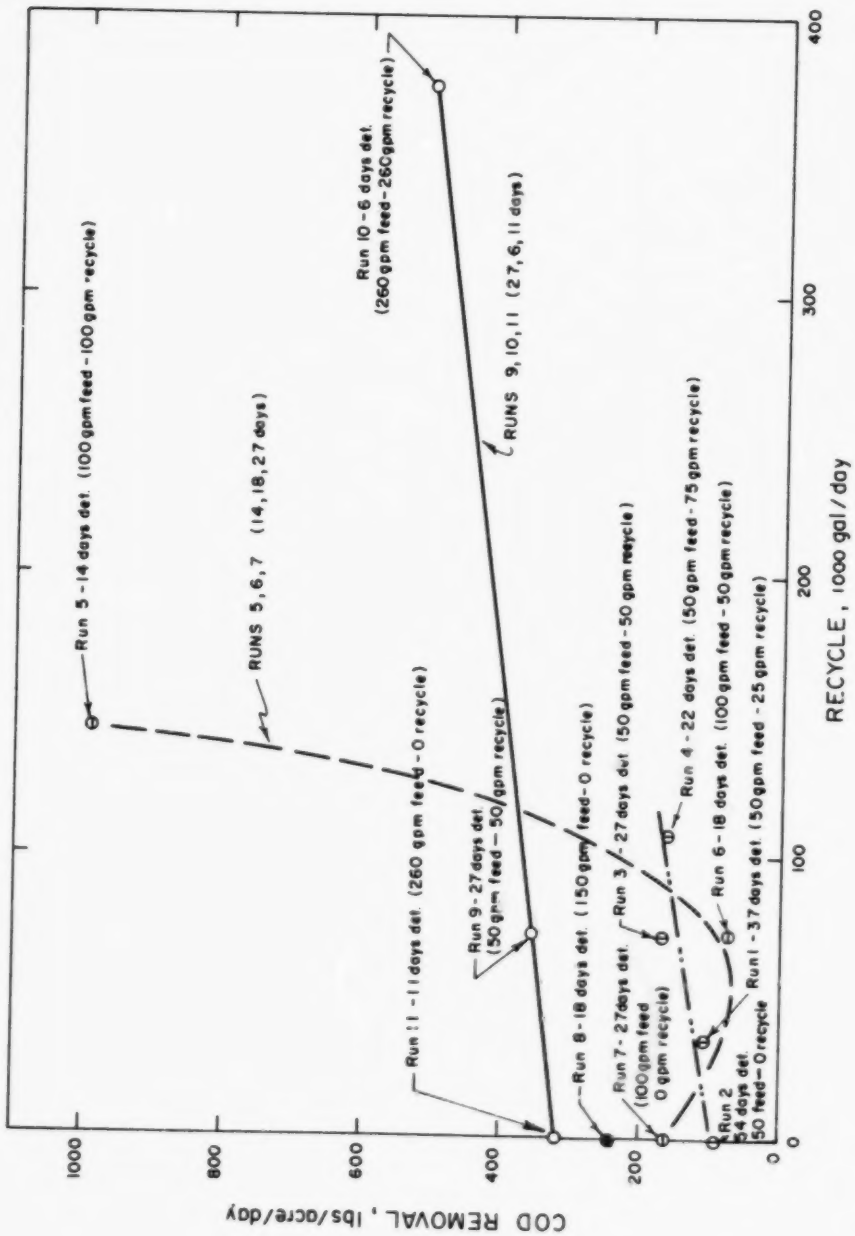
COD REMOVAL, lbs/acre/day
RECYCLE, 1000 gal/day
Run 5 - 14 days det. (100 gpm feed - 100 gpm recycle)
RUNS 5,6,7 (14,18,27 days)
Run 10 - 6 days det. (260 gpm feed - 260 gpm recycle)
RUNS 9,10,11 (27,6,11 days)
Run 11 - 11 days det. (260 gpm feed - 0 recycle)
Run 9 - 27 days det. (150 gpm feed - 50 gpm recycle)
Run 8 - 18 days det. (150 gpm feed - 0 recycle)
Run 7 - 27 days det. (100 gpm feed 0 gpm recycle)
Run 3 - 27 days det. (50 gpm feed - 50 gpm recycle)
Run 4 - 22 days det. (50 gpm feed - 75 gpm recycle)
Run 6 - 18 days det. (100 gpm feed - 50 gpm recycle)
Run 1 - 37 days det. (50 gpm feed - 25 gpm recycle)
Run 2 54 days det. 50 feed - 0 recycle
0
200
400
600
800
1000
100
300

Figure 18. - The influence of recirculation on COD removal in the facultative pond.

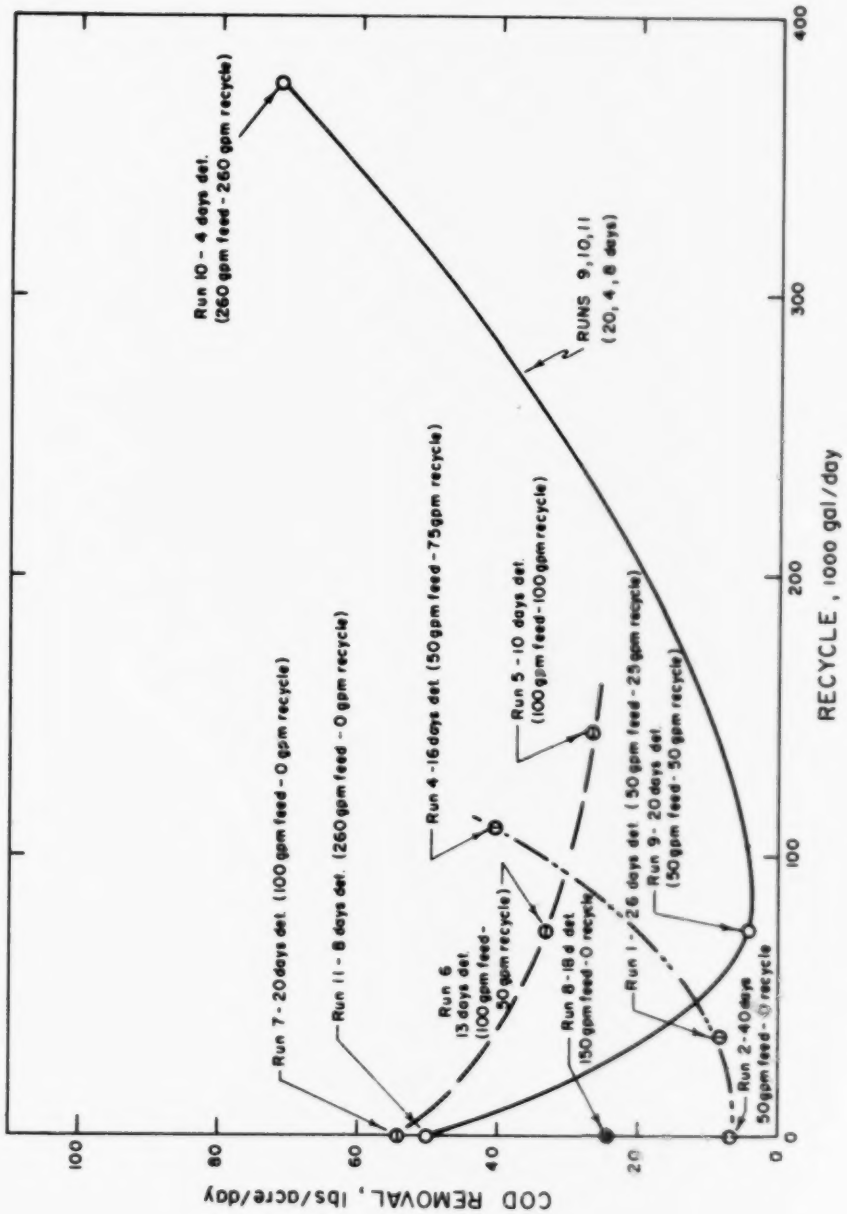
COD REMOVAL, lbs/acre/day
RECYCLE, 1000 gal/day
Run 10 - 4 days det. (260 gpm feed - 260 gpm recycle)
RUNS 9, 10, 11 (20, 4, 8 days)
Run 7 - 20 days det. (100 gpm feed - 0 gpm recycle)
Run 11 - 8 days det. (260 gpm feed - 0 gpm recycle)
Run 4 - 16 days det (50 gpm feed - 75 gpm recycle)
Run 5 - 10 days det. (100 gpm feed - 100 gpm recycle)
Run 6 13 days det (100 gpm feed - 50 gpm recycle)
Run 8 - 18 d det. 150 gpm feed - 0 recycle
Run 1 - 26 days det (50 gpm feed - 25 gpm recycle)
Run 9 - 20 days det (50 gpm feed - 50 gpm recycle)
Run 2 - 40 days 50 gpm feed - 0 recycle

Figure 19. - The influence of recirculation on COD removal in the aerobic pond.

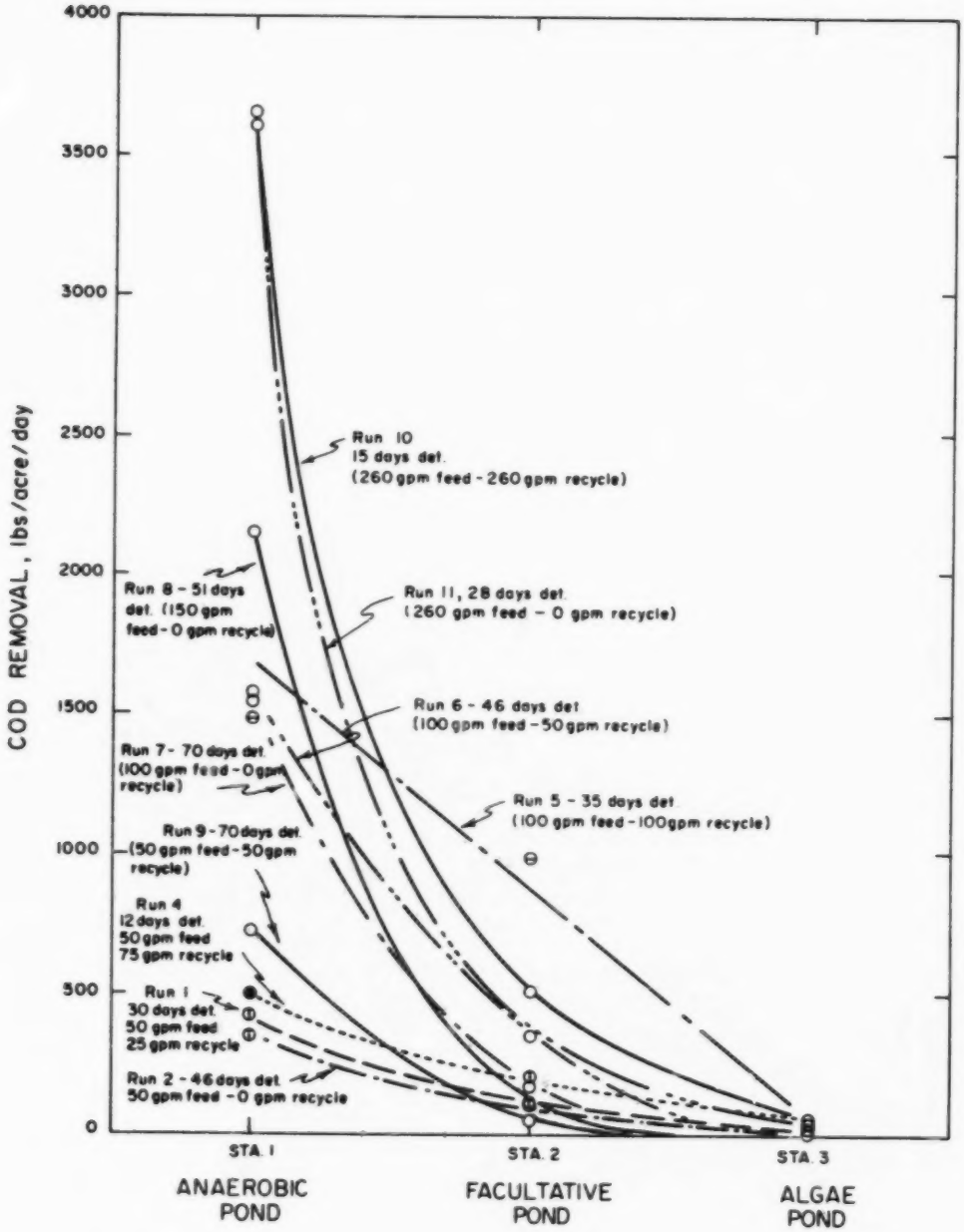
4000
3500
3000
2500
2000
1500
1000
500
0
COD REMOVAL, lbs/acre/day
Run 10
15 days det.
(260 gpm feed - 260 gpm recycle)
Run 8 - 51 days det. (150 gpm feed - 0 gpm recycle)
Run 11, 28 days det. (260 gpm feed - 0 gpm recycle)
Run 6 - 46 days det (100 gpm feed - 50 gpm recycle)
Run 7 - 70 days det. (100 gpm feed - 0 gpm recycle)
Run 5 - 35 days det. (100 gpm feed - 100 gpm recycle)
Run 9 - 70 days det. (50 gpm feed - 50 gpm recycle)
Run 4
12 days det.
50 gpm feed
75 gpm recycle
Run 1
30 days det.
50 gpm feed
25 gpm recycle
Run 2 - 46 days det.
50 gpm feed - 0 gpm recycle
STA. 1
STA. 2
STA. 3
ANAEROBIC POND
FACULTATIVE POND
ALGAE POND

Figure 20. - Effect of the anaerobic, facultative, aerobic series treatment on COD removal for all runs.

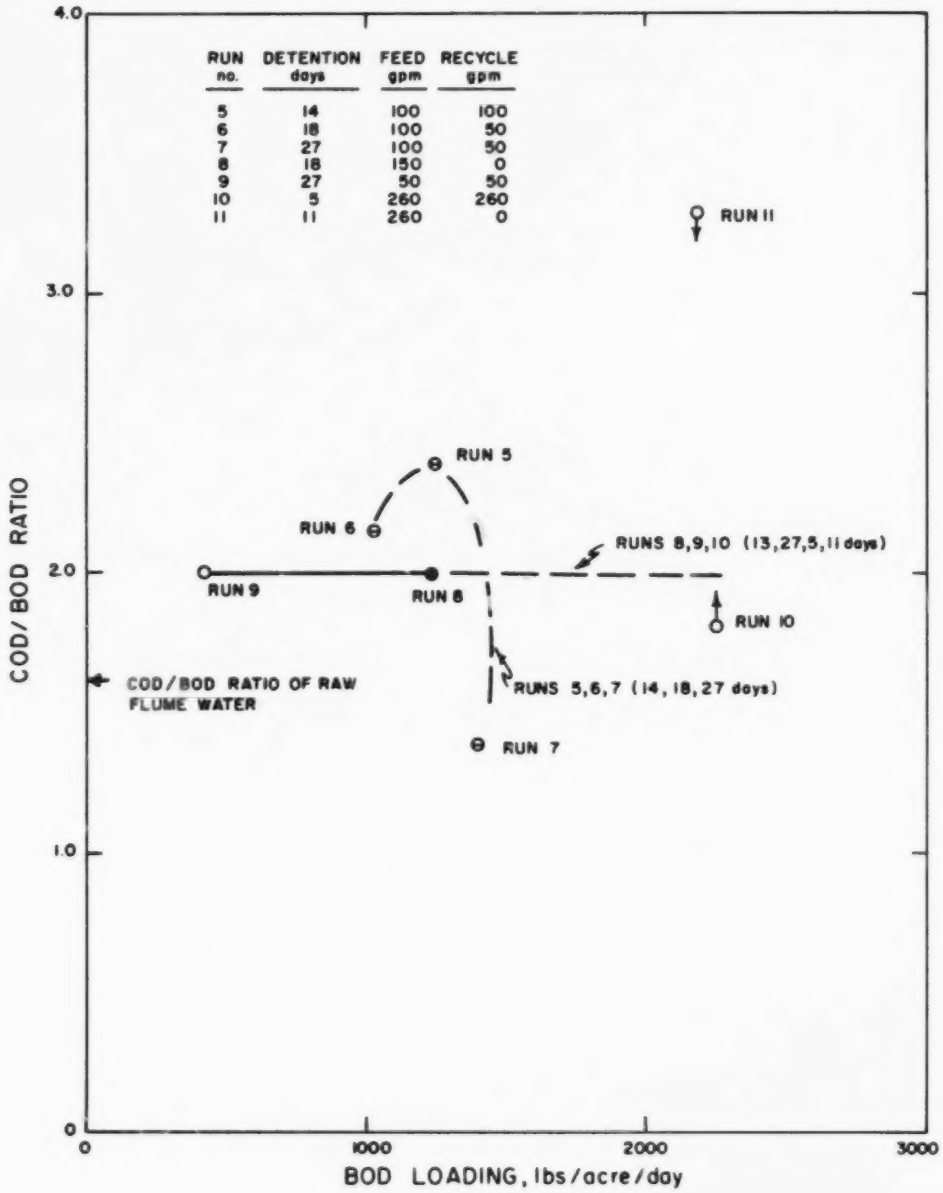

Figure 21. - The influence of BOD loading on the COD:BOD ratio in the anaerobic pond.

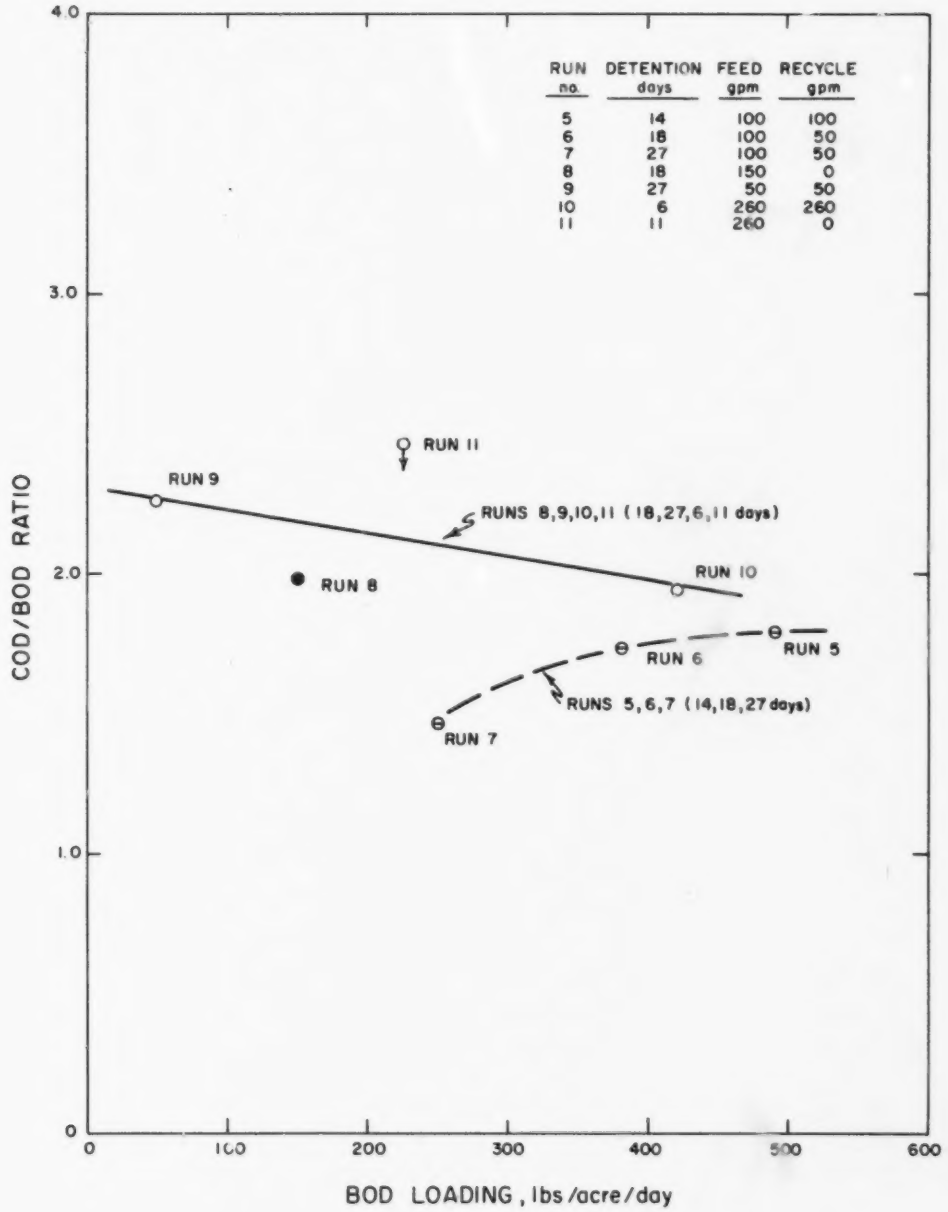

Figure 22. - The influence of BOD loading on the COD:BOD ratio in the facultative pond.

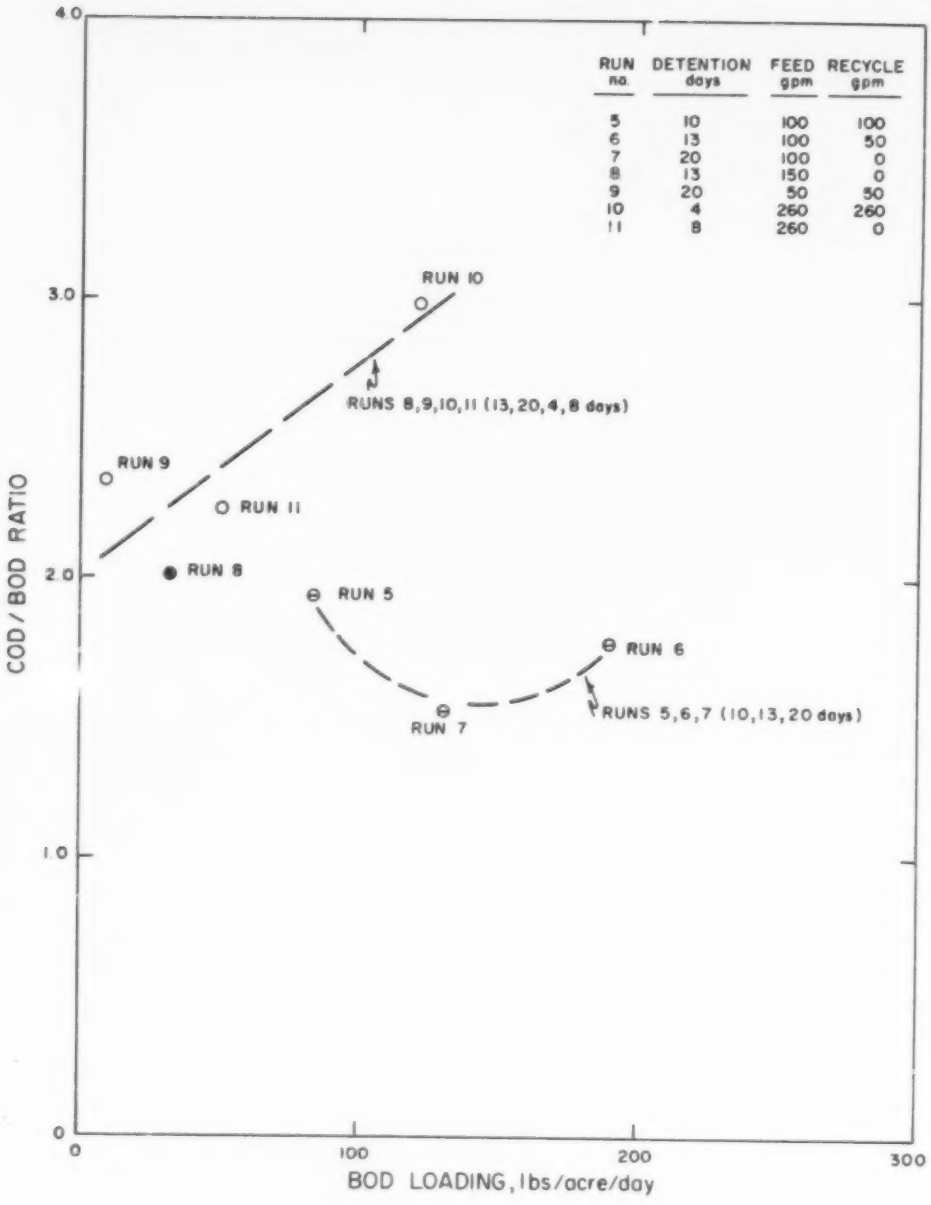

Figure 23. - The influence of BOD loading on the COD:BOD ratio in the aerobic pond.

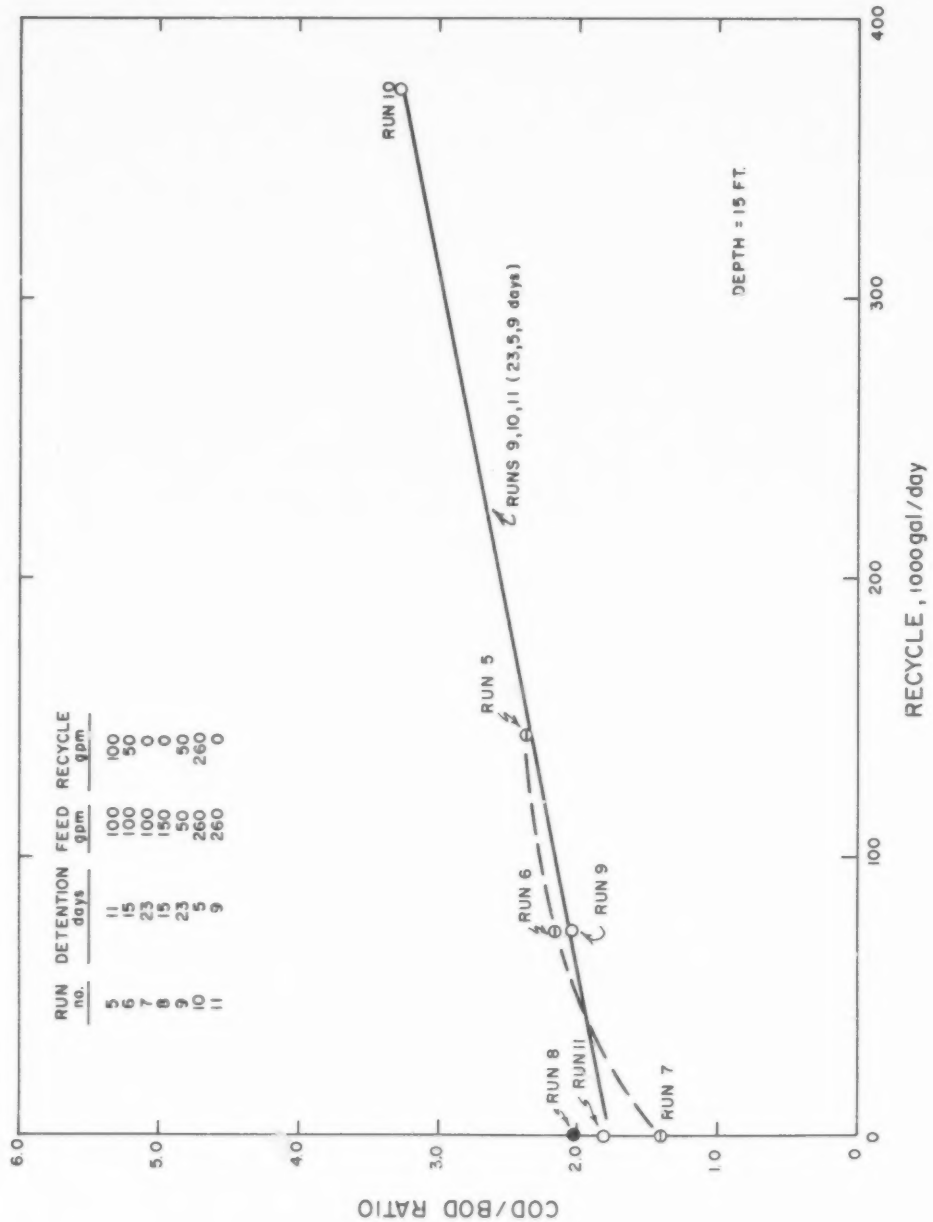

Figure 24. - The relation between recirculation and the COD:BOD ratio in the anaerobic pond.

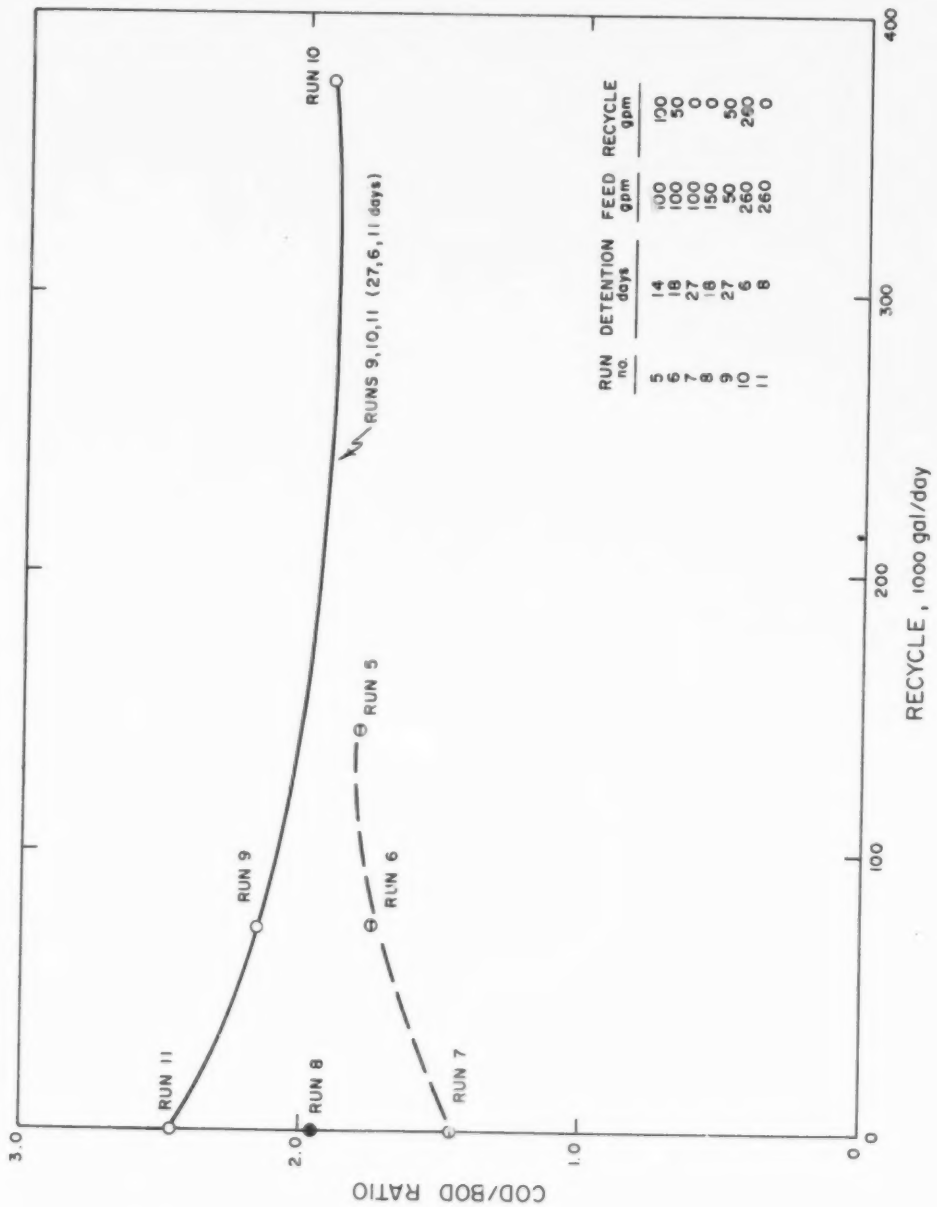

Figure 25. - The relation between recirculation and the COD:BOD ratio in the facultative pond.

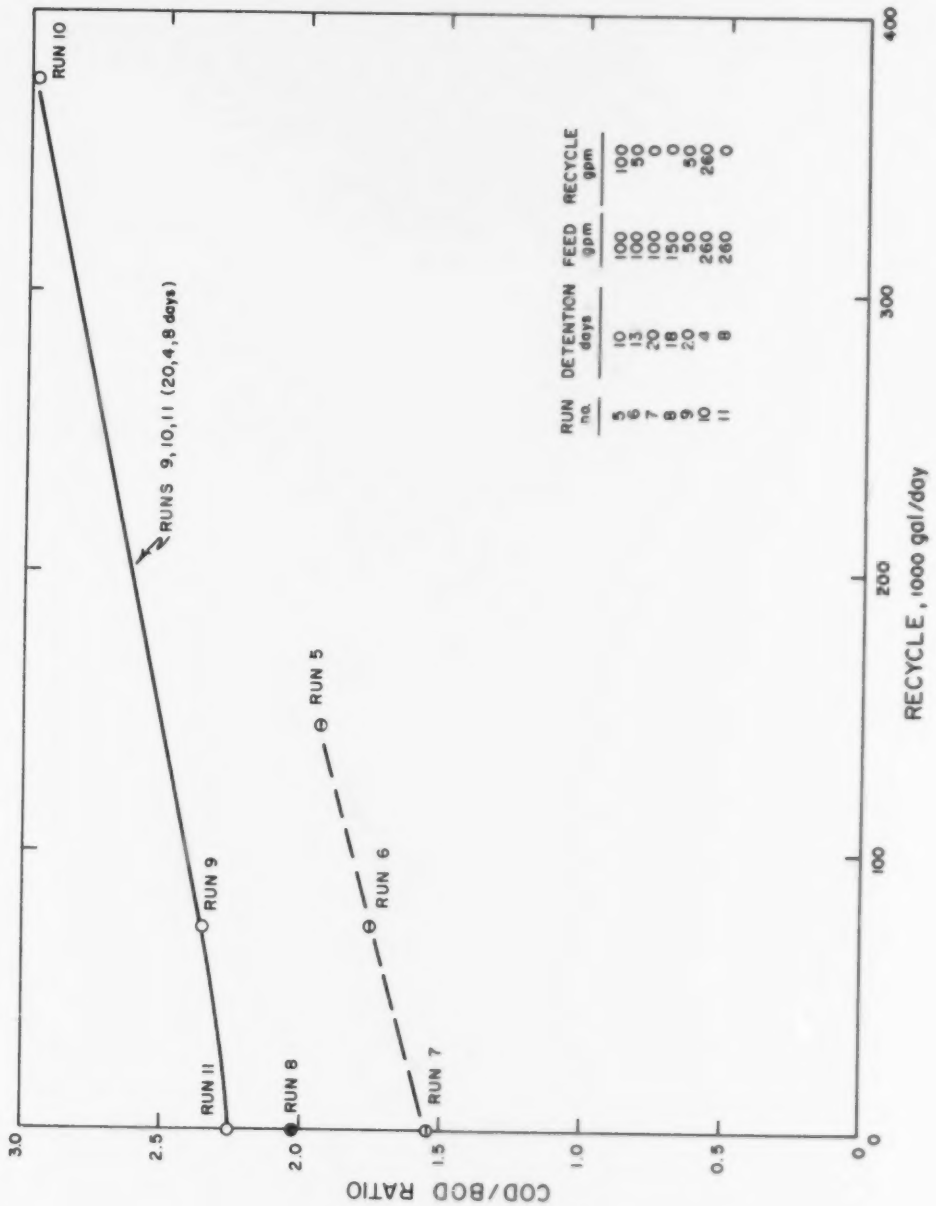

Figure 26. - The relation between recirculation and the COD:BOD ratio in the aerobic pond.

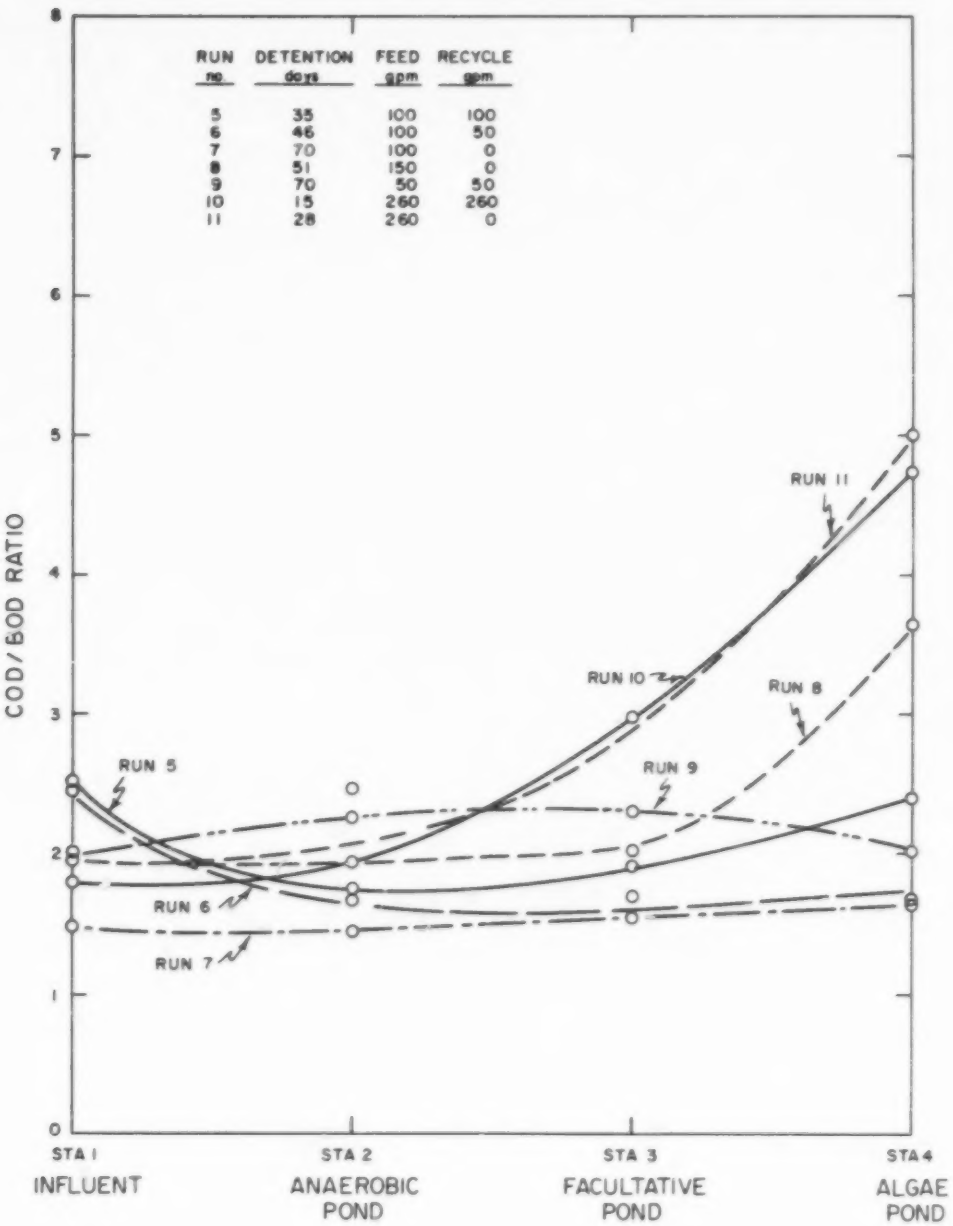

Figure 27. - Effect of the anaerobic, facultative, aerobic series treatment on the COD:BOD ratio.

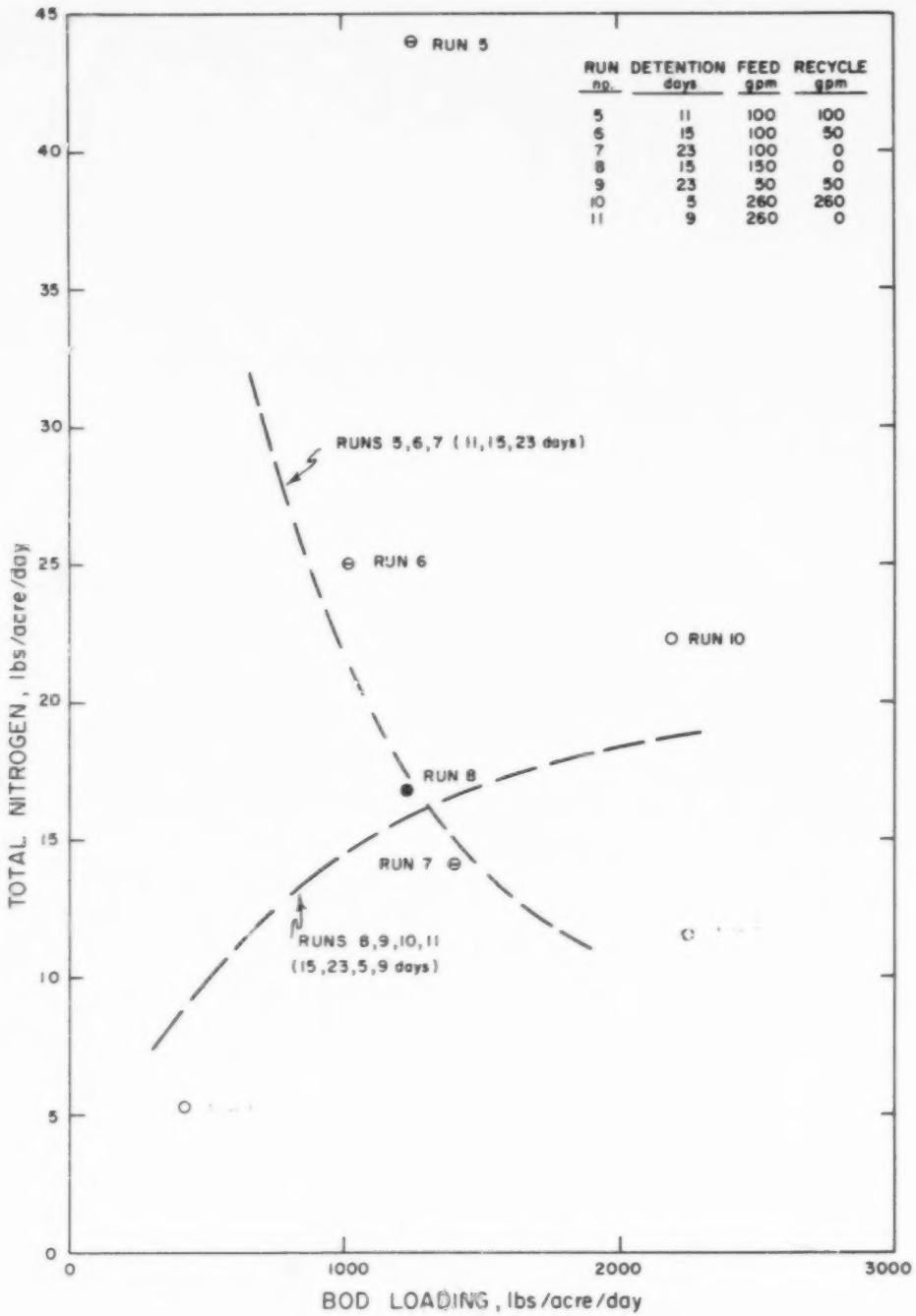

Figure 28. - The relation of BOD loading to the total nitrogen concentration in the anaerobic pond.

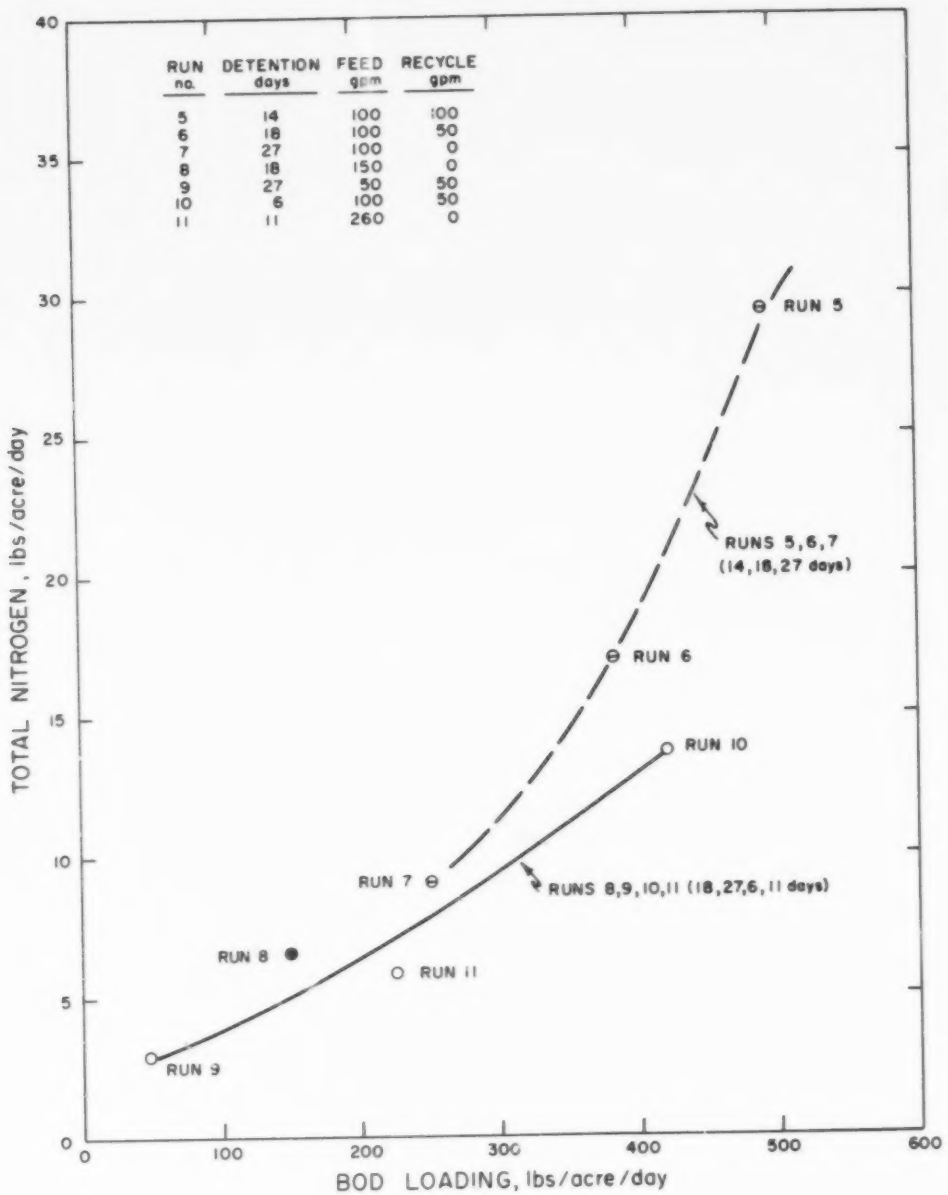

Figure 29. - The relation of BOD loading to the total nitrogen concentration in the facultative pond.

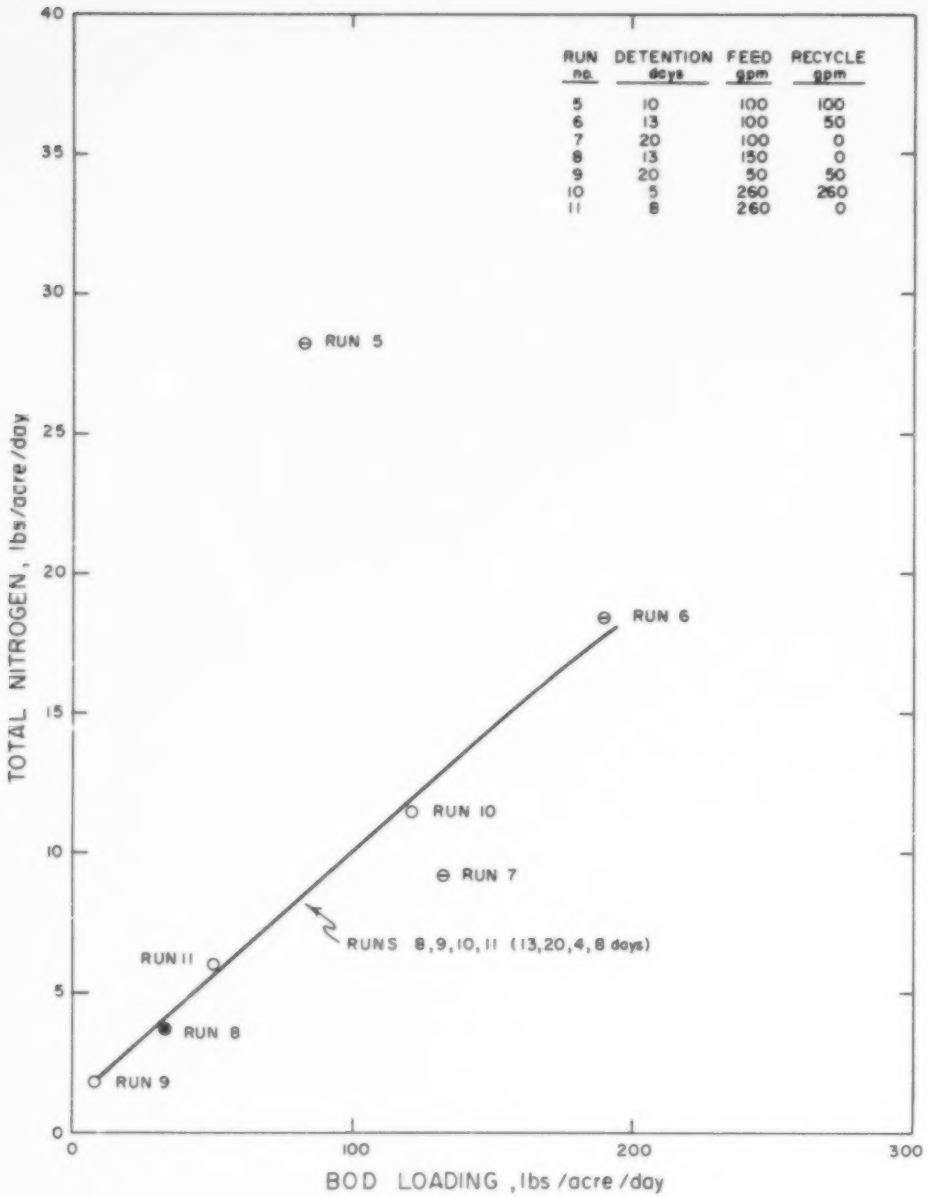

Figure 30. - The relation of BOD loading to the total nitrogen concentration in the aerobic pond.

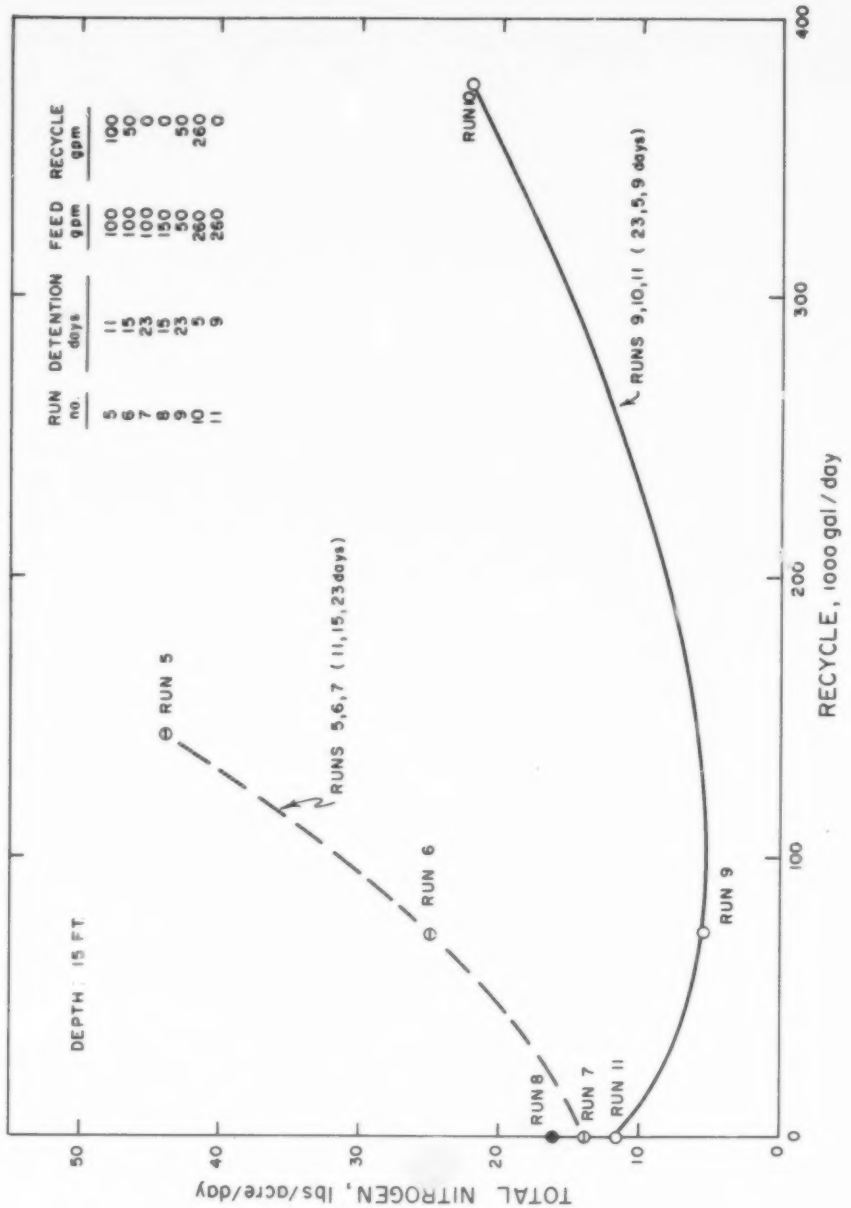

Figure 31. - The relation of recirculation to total nitrogen in the anaerobic pond.

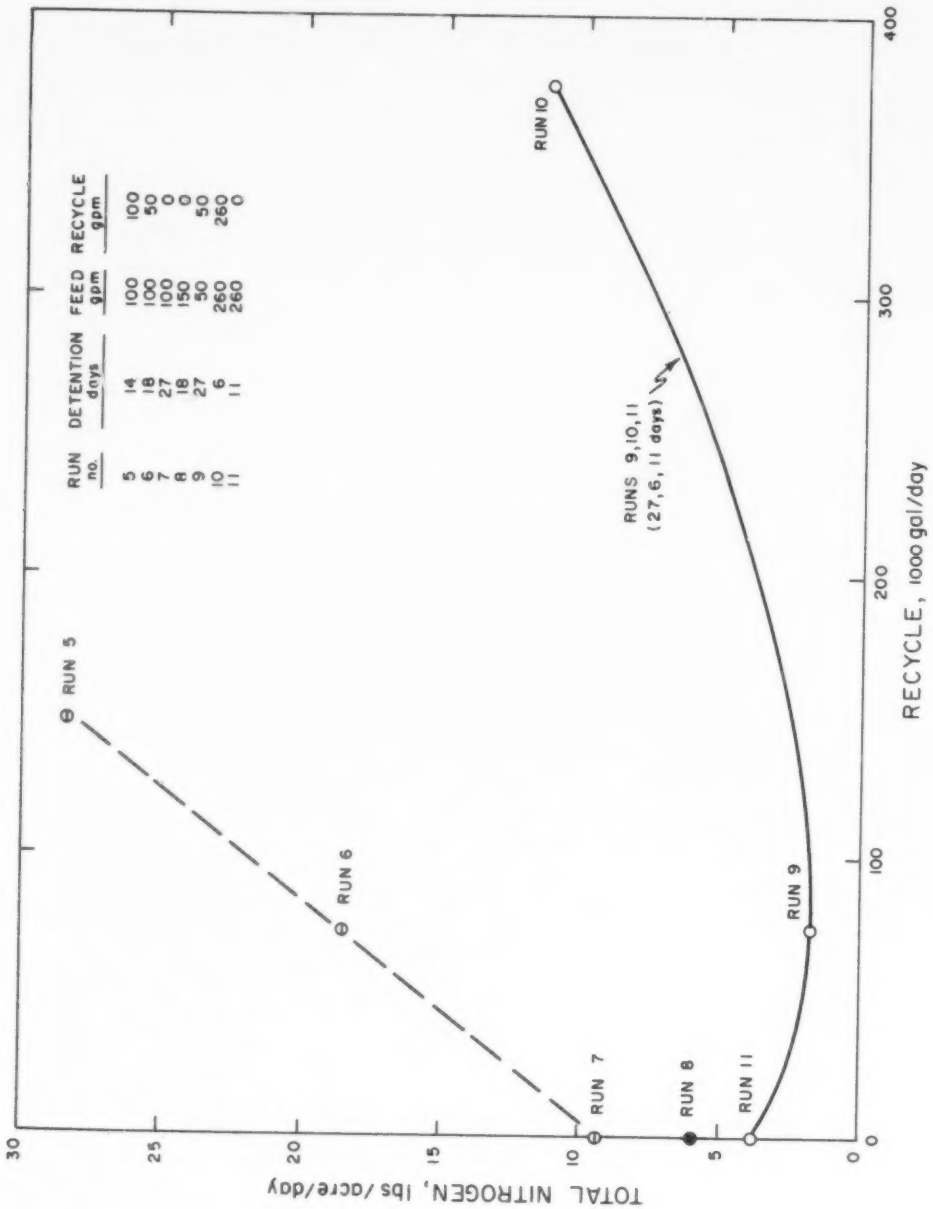

Figure 32. - The relation of recirculation to total nitrogen in the facultative pond.

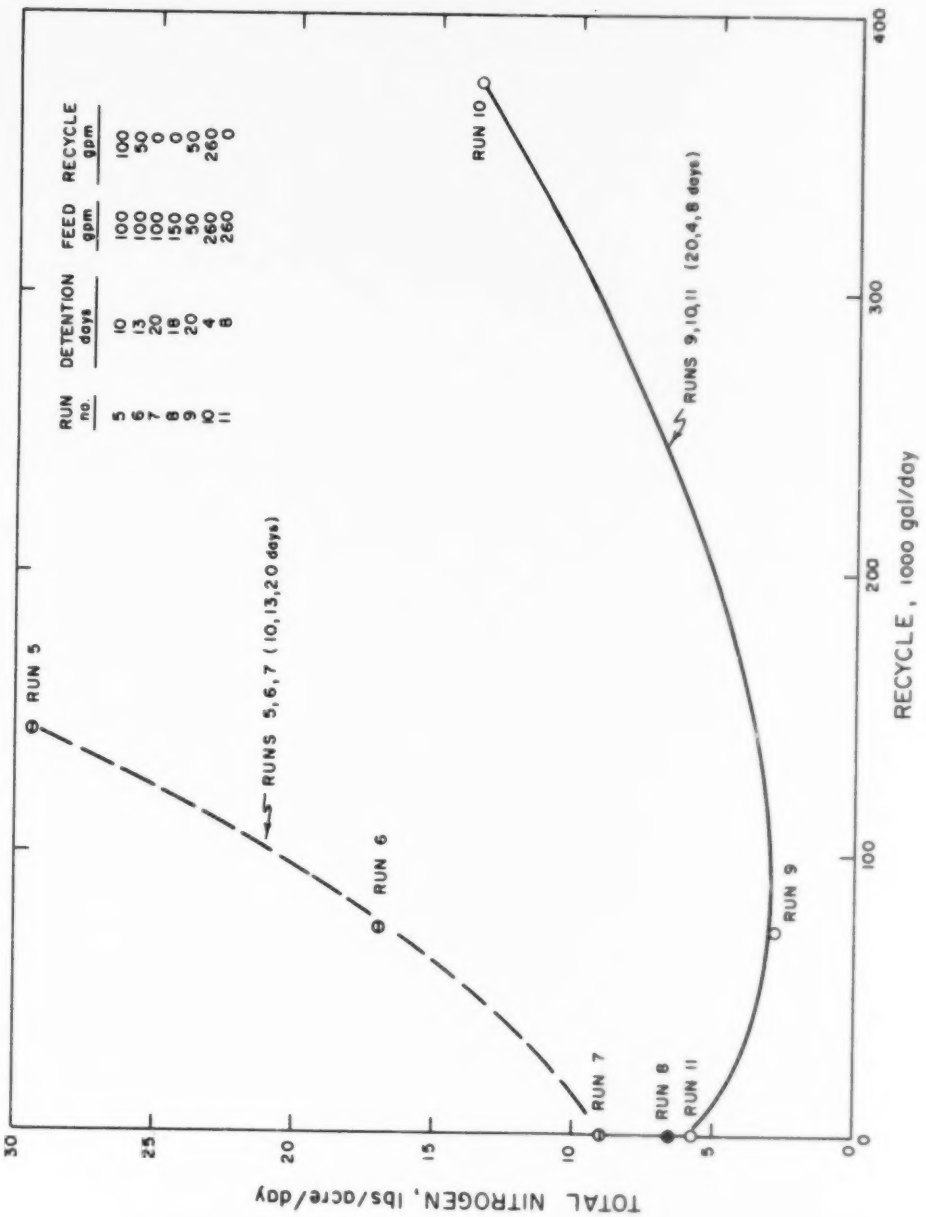

Figure 33. - The relation of recirculation to total nitrogen in the aerobic pond.

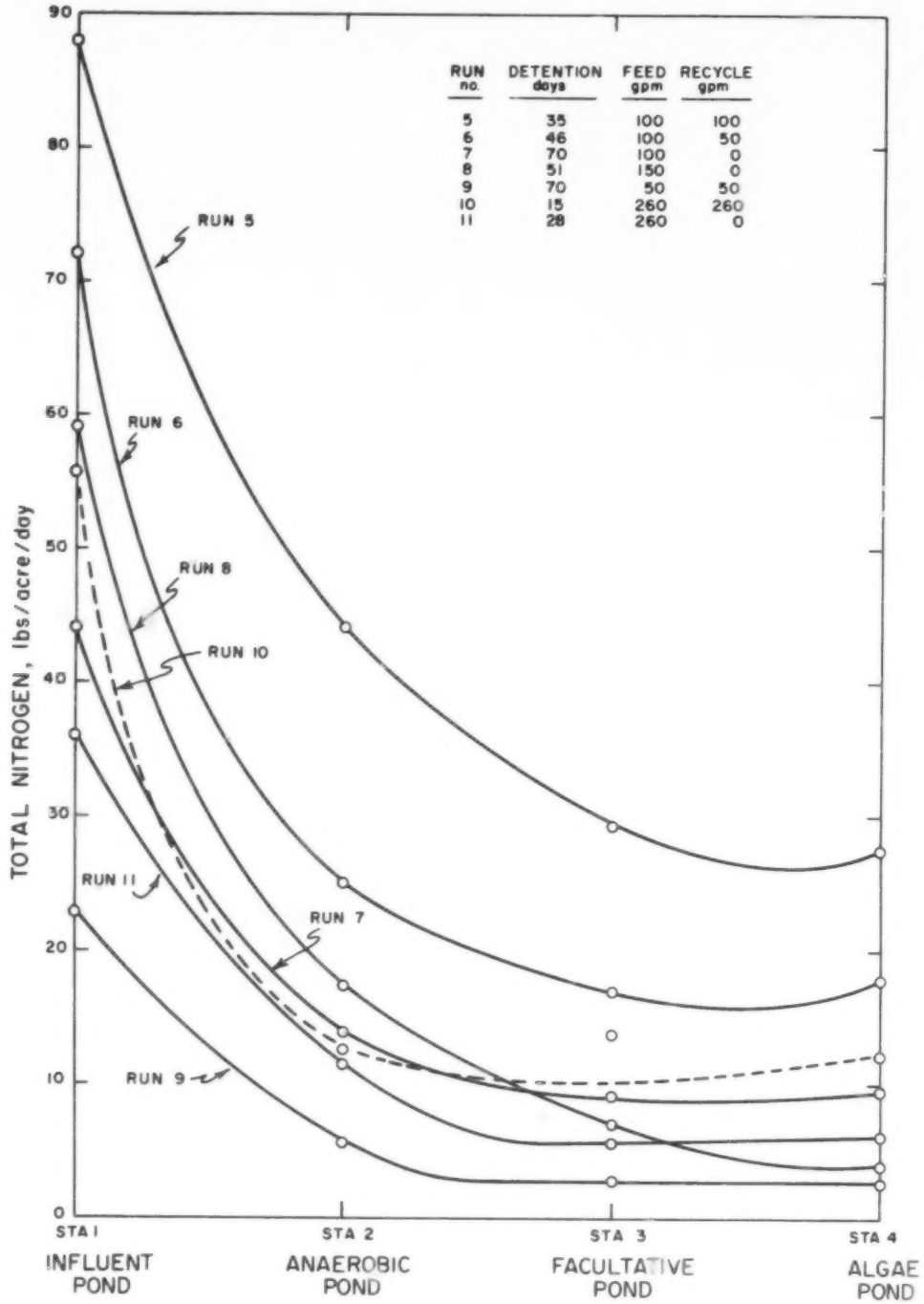

Figure 34. - Effect of the anaerobic, facultative, aerobic series treatment on total nitrogen.

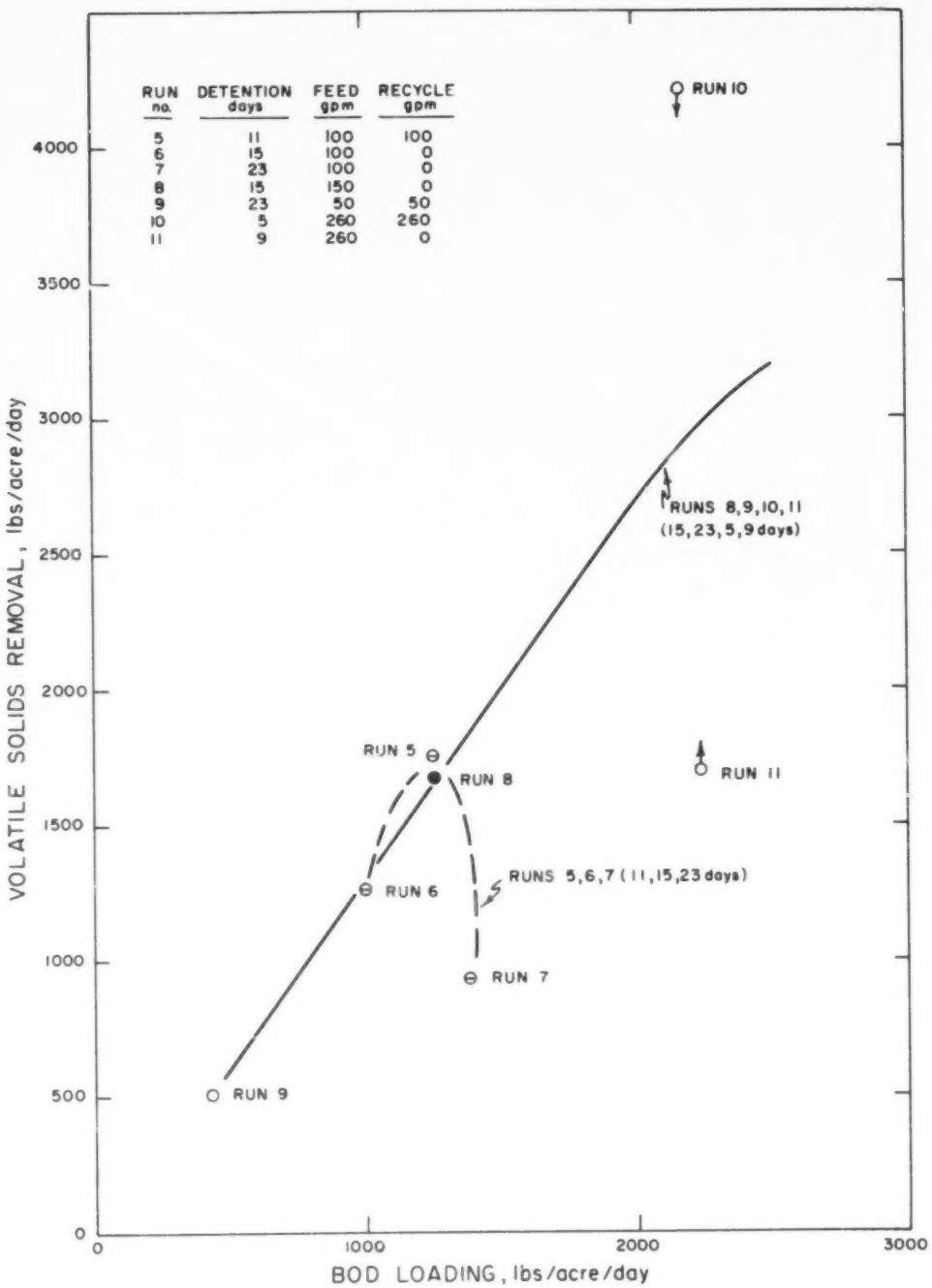

Figure 35. - The influence of BOD loading on volatile solids removal in the anaerobic pond.

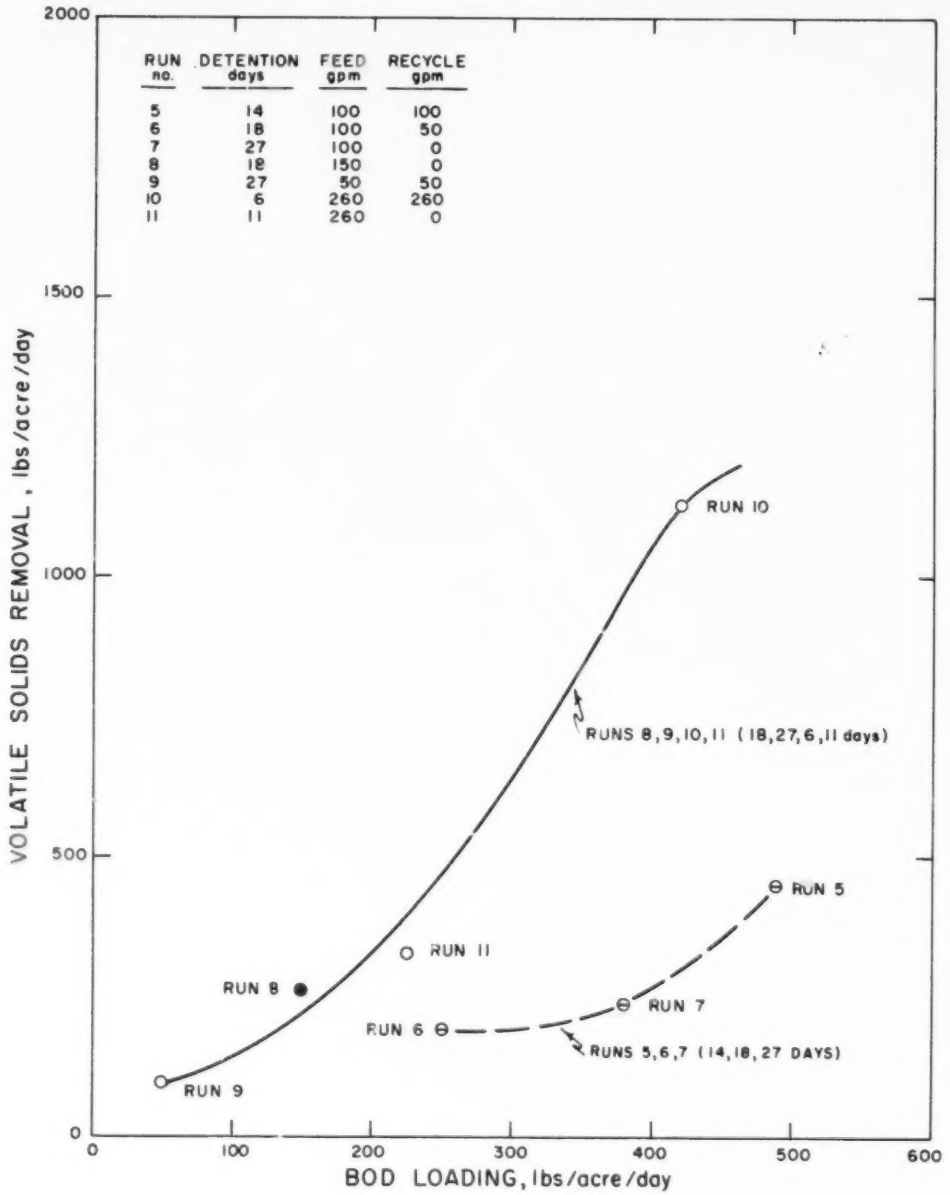

Figure 36. - The influence of BOD loading on volatile solids removal in the facultative pond.

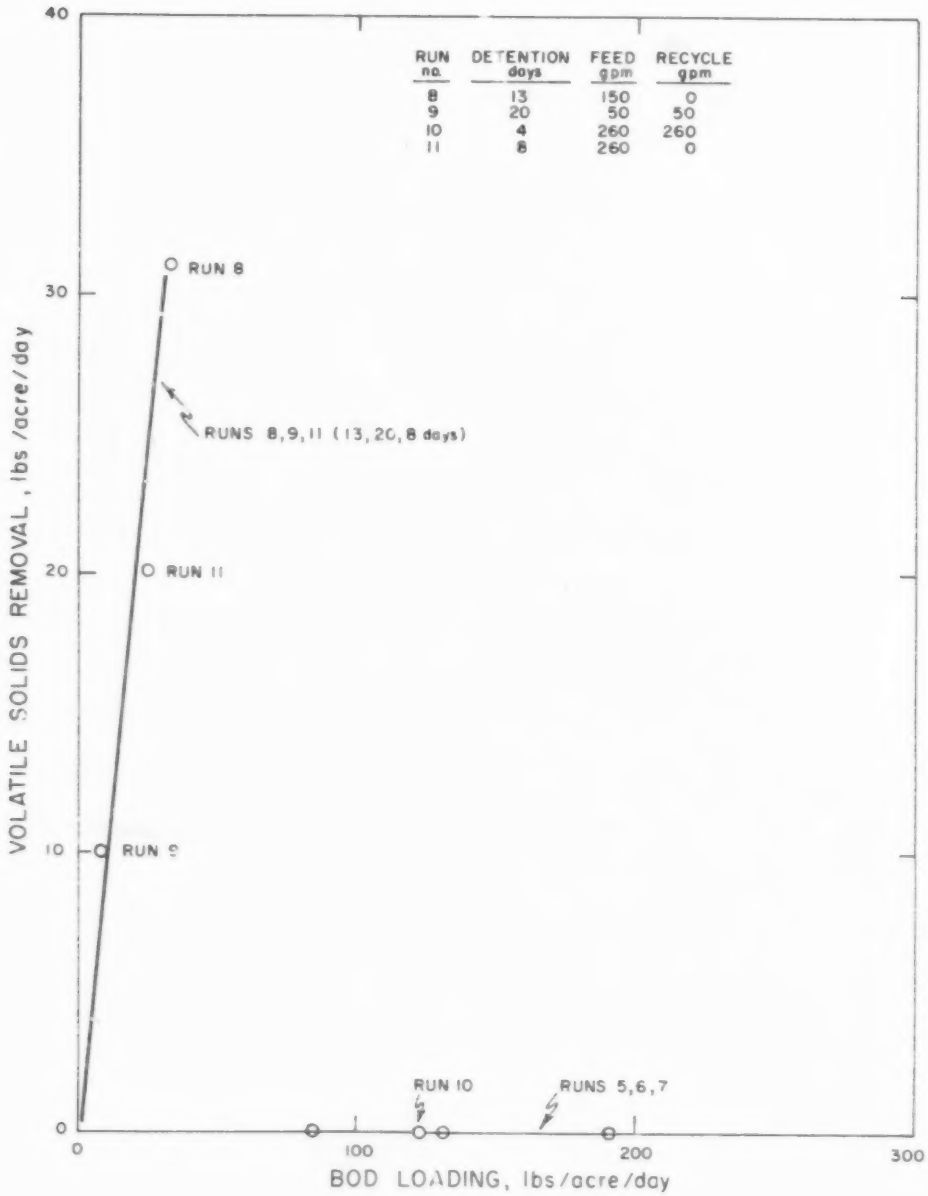

Figure 37. - The influence of BOD loading on volatile solids removal in the aerobic pond.

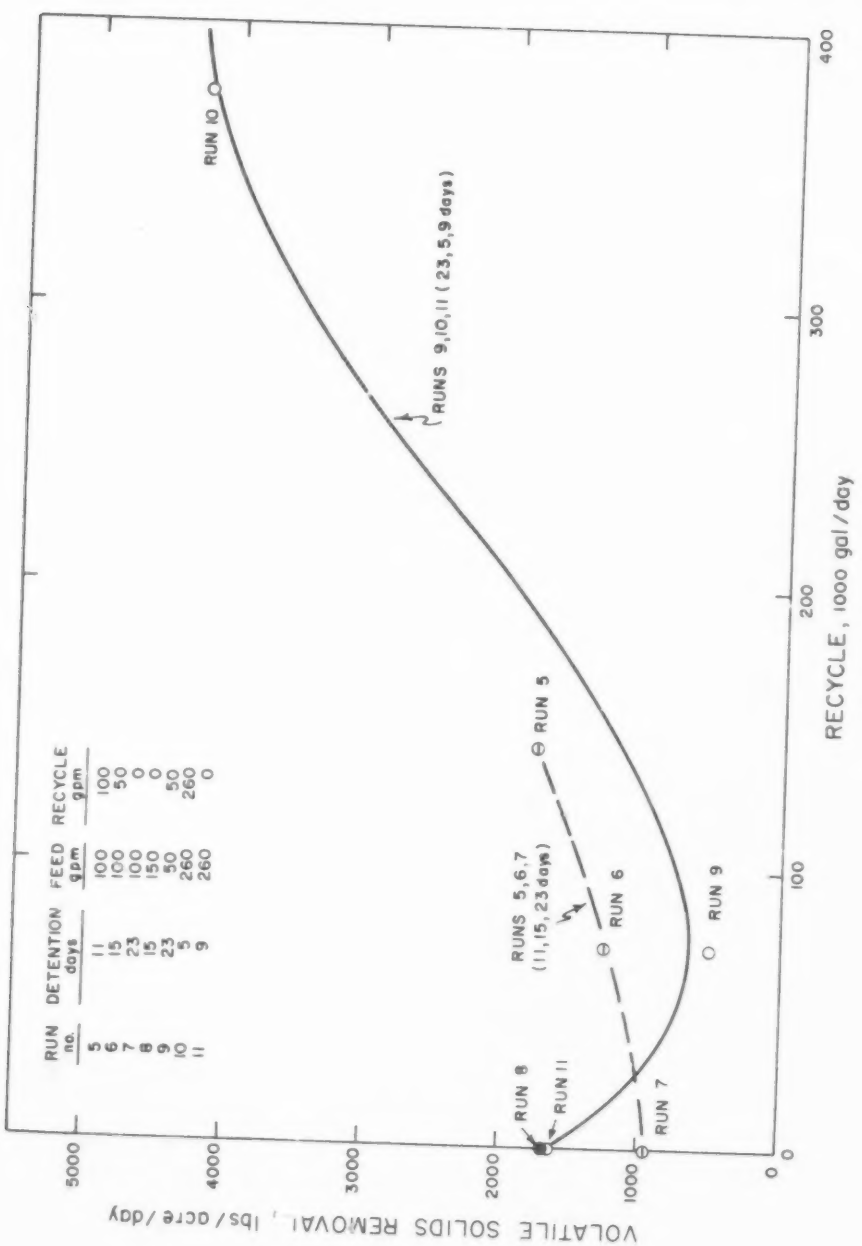

Figure 38. - The relation of recirculation to volatile solids removal in the anaerobic pond.

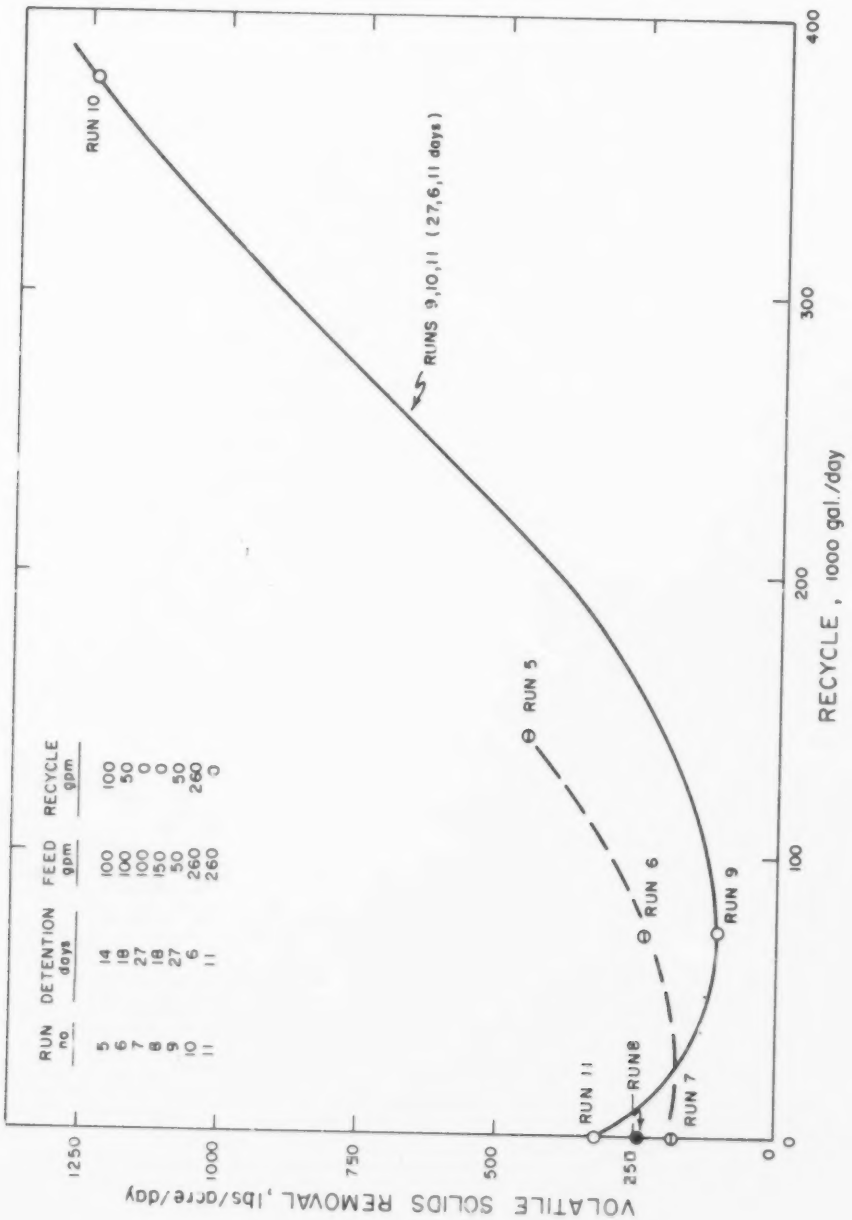

Figure 39. - The relation of recirculation to volatile solids removal in the facultative pond.

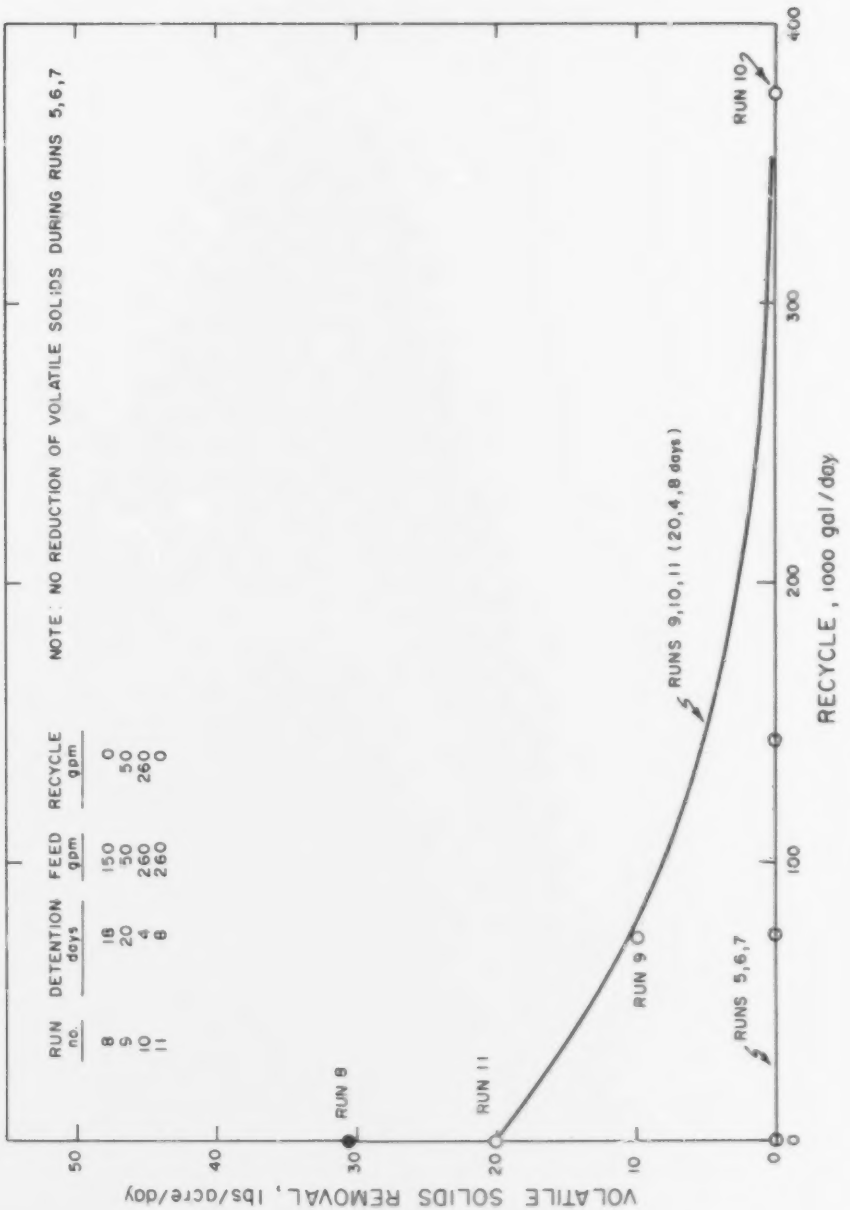

Figure 40. - The relation of recirculation to volatile solids removal in the aerobic pond.

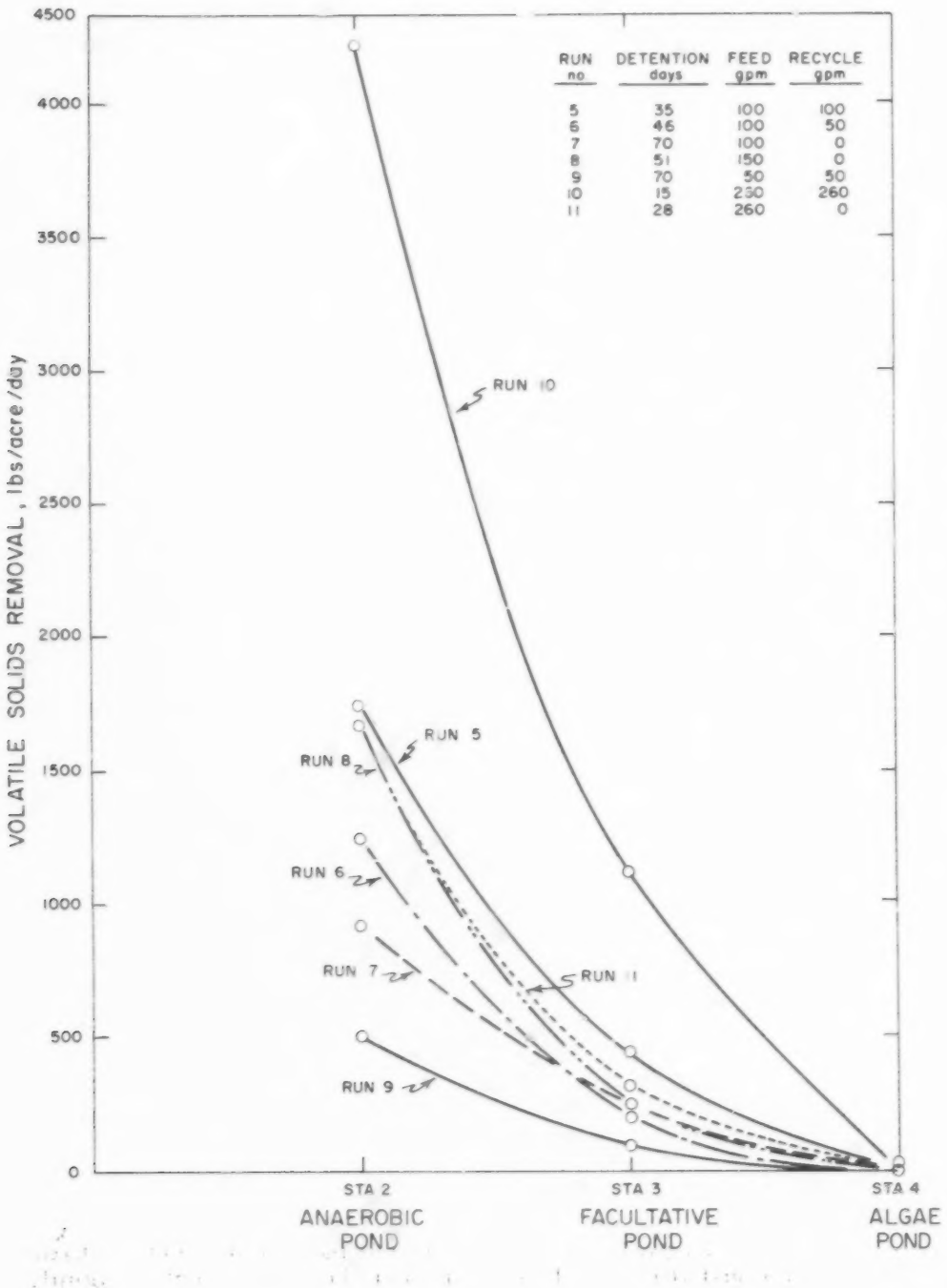

Figure 41. - Effect of the anaerobic, facultative, aerobic series treatment on volatile solids removal.

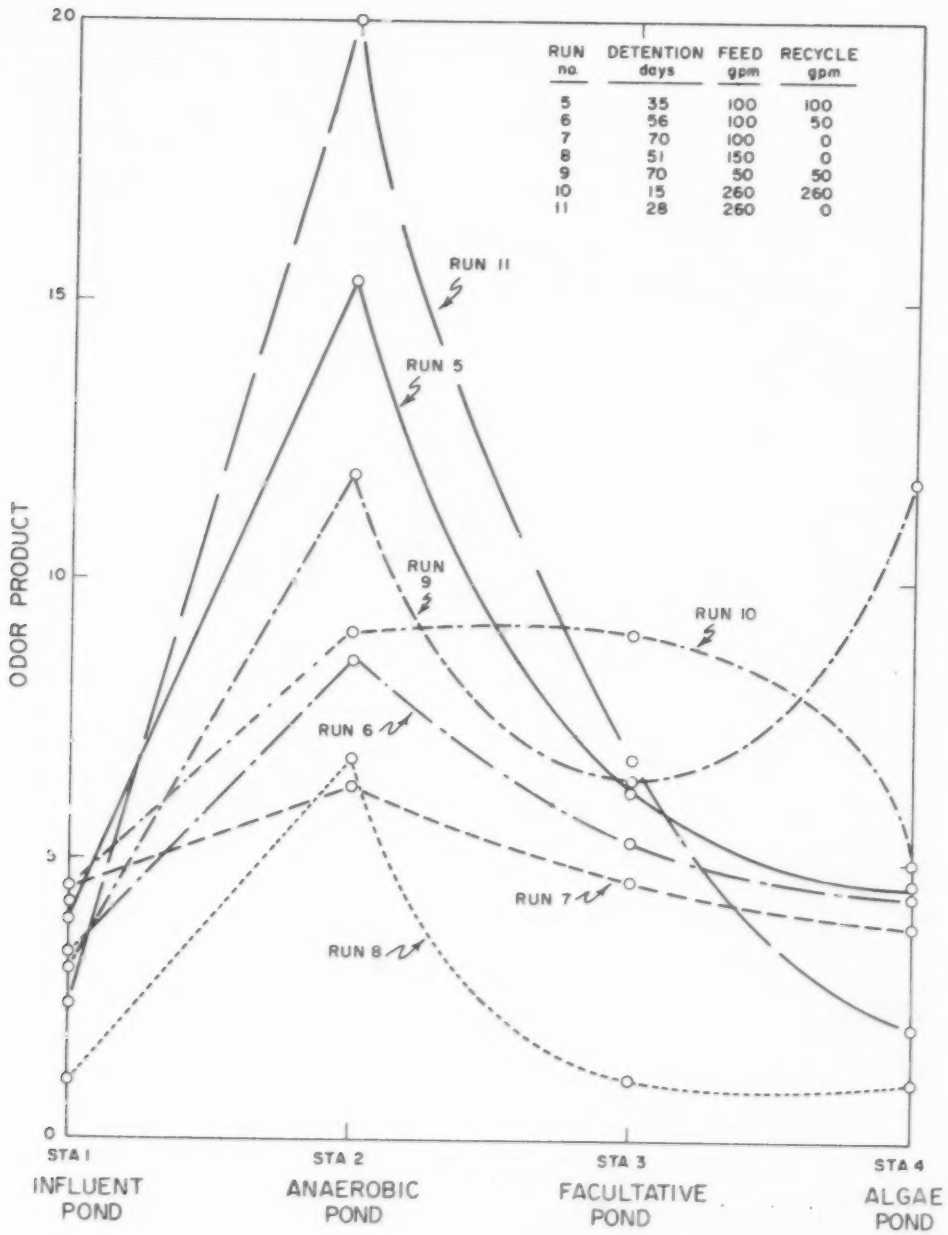

Figure 42. - The relation of "odor product" to the anaerobic, facultative, aerobic series treatment.

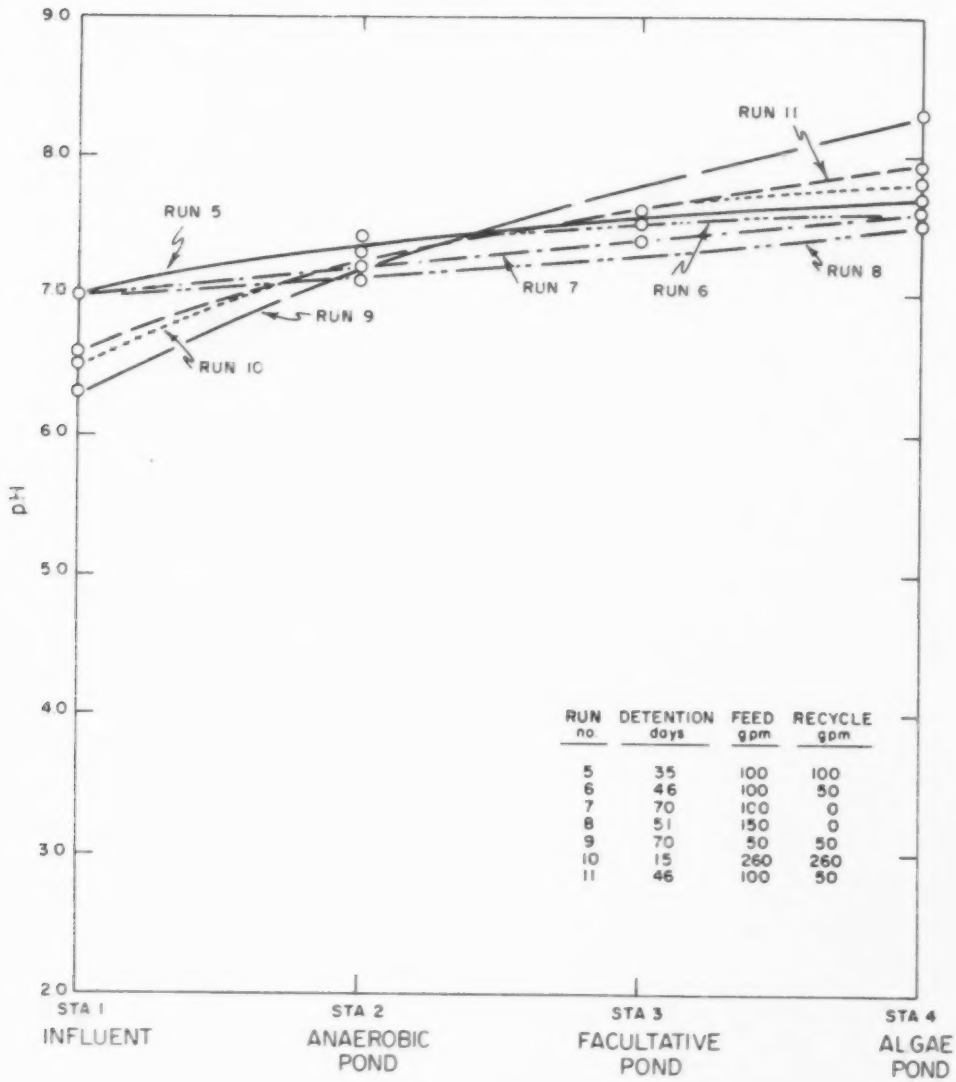

Figure 43. - The effect the anaerobic, facultative, aerobic series treatment on pH.